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The Geomorphology of the Wyoming-Lackawanna Region

By

HARRY AUGUSTUS ITTER

Department of Internal Affairs
THOMAS A. LOGUE, *Secretary*
Topographic and Geologic Survey
GEORGE H. ASHLEY, *State Geologist*

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PREFACE

The Wyoming-Lackawanna Valley is perhaps best known to geologists as the Northern Anthracite Field of Pennsylvania. Because nearly all the valley is underlain by many beds of high grade anthracite it has long been the site of extensive geological work carried on by the State and Federal Geological Surveys. Geologists employed by these organizations have for the most part concerned themselves with structural and economic problems incident to the removal of the coal, hence other problems have been somewhat neglected.

It is the writer's belief that although the economic life of the valley centers on the mining of coal, nevertheless there are those who are eager to learn how the features of the landscape which they daily see came into being. This paper must not be construed as one dealing with the economic geology of the area, but as a paper dealing with the problems associated with the development of the land forms.

The paper is developed along two different lines. Part I has been written primarily for the layman residing in the region who has had little or no geologic training. It describes and discusses the salient topographic features of the area and their mode of origin. No detailed explanations as to the various lines of evidence on which the conclusions are based are included, since for many years the greater portion of the material has been property common to geologists working in Appalachian fields. This treatment, it is hoped, will be found satisfactory as a non-technical summary of the evolution of the Wyoming-Lackawanna landscape. Part II deals with certain important geomorphic problems of the area presented in a manner somewhat more technical than in Part I. Recognition of these problems and investigation leading to their rational solution comprises the original research and contribution of the writer. It will be understood that the reader of this second section shall have had a reasonable amount of training along geologic lines in order properly to understand the argument. For those readers who may find their interests aroused along any of the lines suggested in Part I, a Bibliography is appended.

A classic work dealing with the evolution of land forms of this region is the scholarly essay of W. M. Davis on "The Rivers and Valleys of Pennsylvania," published in 1889. The general conclusions reached by Davis went largely unchallenged until 1931 when a new theory of Appalachian evolution was proposed by Professor Douglas Johnson of Columbia University, in his work entitled "Stream Sculpture on the Atlantic Slope."

The Wyoming-Lackawanna area presents a number of problems relating to the major drainage. These should be examined in the light of the Davisian and Johnsonian theories, and should fit into the scheme suggested by one or the other, or else indicate the need for yet another interpretation. The writer has studied these problems in detail in an attempt to find what theory most adequately and rationally explains them.

The general discussion dealing with the erosional history of the region is based on concepts originally developed by William Morris Davis and modified to some extent by the studies of Douglas W. Johnson. More recent investigations, particularly those of Dr. George H. Ashley, seem to indicate that there may possibly have been but one peneplane high above any present level and that the present accordant surfaces (Schooley, Harrisburg, Somerville peneplanes of the older concept) are the result of differential erosion and do not represent peneplanes in the usual meaning of the term.

If the Fall Zone Peneplane of Johnson is conceded to be the same as this older higher peneplane of Ashley, the sequence of events as indicated in this paper will in general hold true. The reader will bear in mind that instead of having several periods of Tertiary peneplanation, each interrupted by specific uplift, there will be but one extensive erosional period and the accordant surfaces as seen today must be construed as the result of differential erosion.

The field work carried on in preparation for this paper was done in the summers of 1930 and 1931 under the auspices of the Pennsylvania Geological Survey. A considerable portion of the summer of 1930 was spent in the valley itself in a study largely devoted to glaciation. Much of the work of 1931 was devoted to major features relating to the broader physiographic aspects of the area.

Prior to the field work in 1931 the writer had constructed a series of projected profiles of the region, each one representing the highest profile of the land surface along a zone one mile in width. The profiles were constructed according to the system of multiple projected profiles devised at Columbia University for the study of erosional surfaces.

The writer wishes to acknowledge his indebtedness to Professor Douglas W. Johnson of Columbia University who suggested the study and under whose supervision the manuscript was prepared; to the officers of the Wyoming Geological and Historical Society who proffered the use of their library facilities; to the late Mr. R. N.

Davis of Scranton who gave of his time to point out features of interest in the Scranton region; to Professor Freeman Ward of Lafayette College whose discussions did much to clarify the writer's own ideas; to the various anthracite operators who so kindly placed many of their private records at the writer's disposal; and to Dr. George H. Ashley, of the Pennsylvania Geological Survey whose interest in this region and in the problems of Appalachian history has made the publication of this paper possible.

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THE GEOMORPHOLOGY OF THE WYOMING - LACKAWANNA REGION

By HARRY AUGUSTUS ITTER

PART I

EVOLUTION OF THE LANDSCAPE IN THE WYOMING-LACKAWANNA REGION

THE WYOMING-LACKAWANNA LANDSCAPE

LOCATION

The Wyoming-Lackawanna Valley is located in the northeastern portion of Pennsylvania. It is included virtually within Lackawanna and Luzerne Counties, barely extending into Susquehanna County on the northeast and Columbia County on the southwest. The geographical relationships are shown on Figure 1.

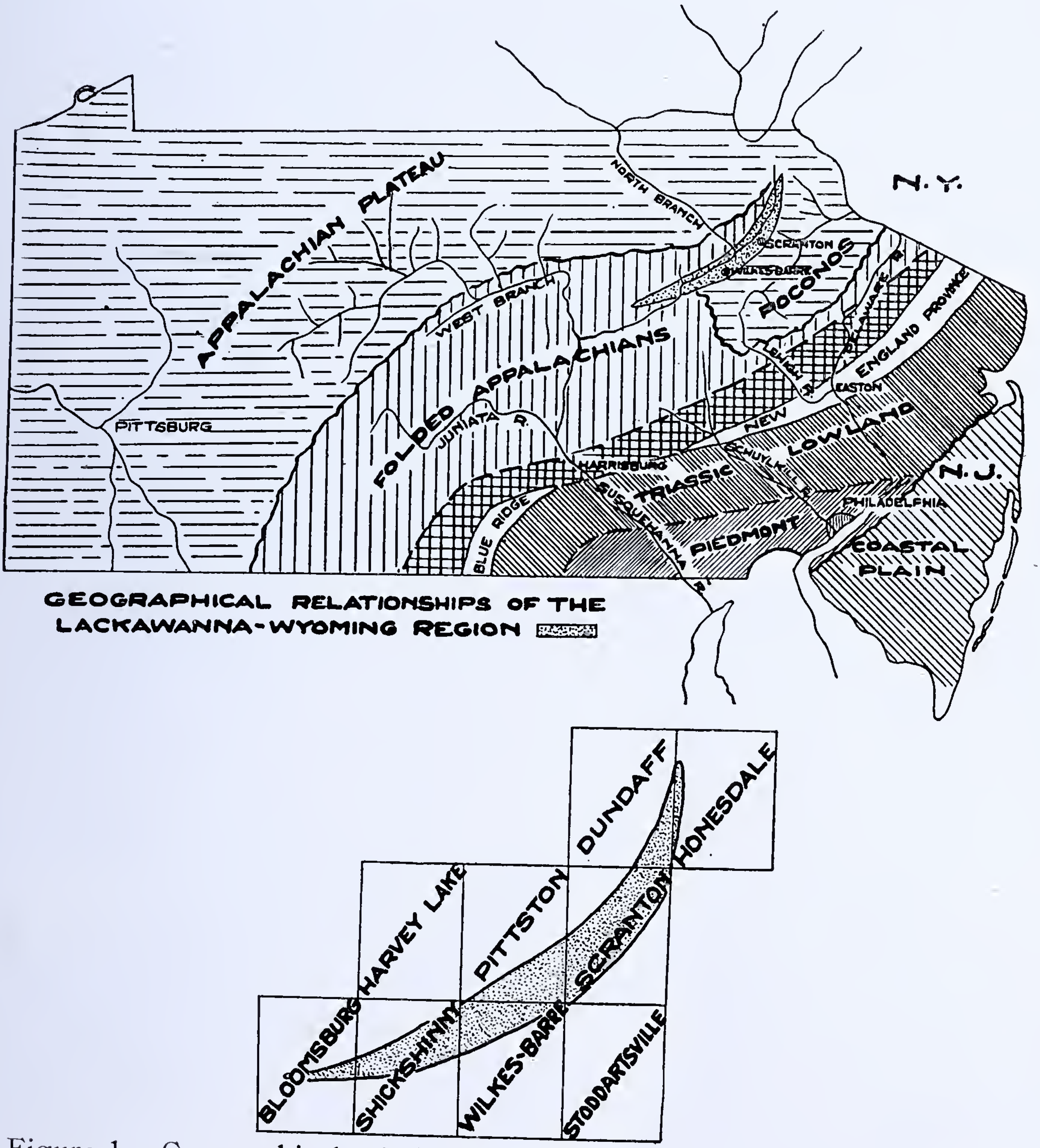


Figure 1. Geographical relationships and location of the Wyoming-Lackawanna region on U.S.G.S. topographic maps.

The valley and the immediately adjacent territory is normally included in the Folded Appalachian Physiographic Province. The northeastern and southeastern mountain rims, however, merge with the Pocono plateau, the eastward extension of the Allegheny plateau, so that all this region might rightly be included within the Plateau Province.

The area under discussion is represented on the United States Geological Survey topographic quadrangles indicated in Figure 1.

THE VALLEY

The Wyoming-Lackawanna Valley has frequently been regarded as a simple structural valley, the result of the folding movements which created the Appalachian Mountains and left this basin as a relic of one of the downwarps. In the earlier stages of Appalachian evolution this probably was the case. Certainly, however, its subsequent history and development have not been so simple as formerly supposed.

This long, curving crescent-shaped valley begins several miles above the northeastern end of the anthracite field, where the prow of the canoe-shaped bordering mountains is breached and the Lackawanna River enters the valley. It extends southwestward a distance of 56 miles to where the Pocono sandstone ridges which form the encircling mountain rim once more meet and terminate the valley.

THE MOUNTAIN RIM

The valley is rimmed about in part by two pairs of mountain ridges and resembles somewhat a crescent-shaped dish which has one great outer rim and a lower inner rim. This character, however, is restricted to the southwestward portion. In the northeastern half the two rims practically coalesce and the two-rim character of the valley edge is nearly if not entirely lost. Structurally the bottom of the dish pitches eastward from the western end and southwestward from the northeast end, the approximate axis of the downfold being located near the center.

The outer higher rim, the one always noted, is made up of a very hard resistant sandstone and conglomerate known as the Pocono formation. This formation surrounds the anthracite fields and forms many of the long narrow ridges of eastern Pennsylvania. The inner rim, not always well defined and sometimes lost sight of because of its somewhat inferior hardness as compared with the Pocono, is composed of the Pottsville formation. It, like the Pocono, constitutes the rock holding up many of the eastern Pennsylvania ridges. Between the two hard formations is a softer formation, the Mauch Chunk red

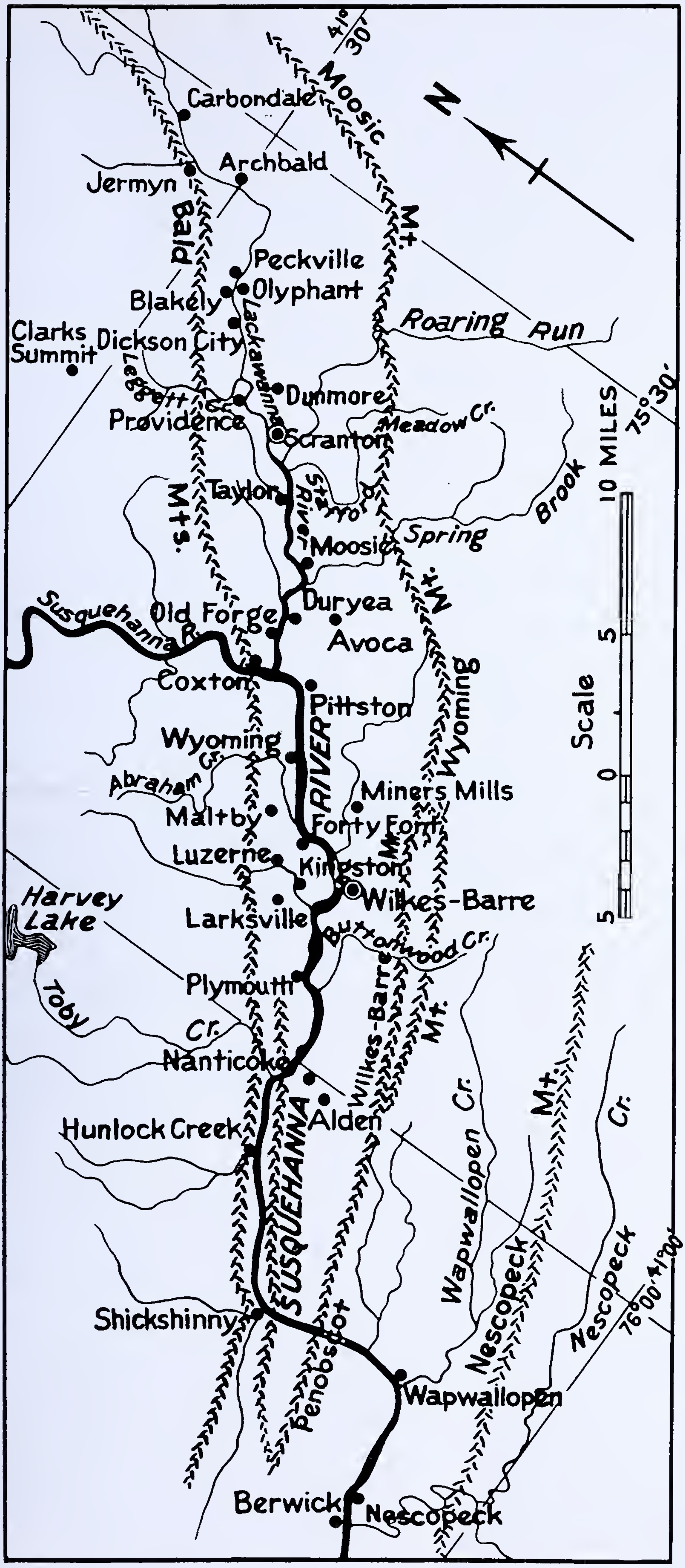


Figure 2. Map of the Wyoming-Lackawanna Valleys.

shale, which wears away more rapidly than the others and forms the valley between the Pocono and Pottsville formations. The Susquehanna River has taken advantage of this weak rock belt by developing its course along the Mauch Chunk formation in the southwestern part of the area. Otherwise the formation is usually exposed in this area in a high narrow valley along the mountain sides.

The mountains constituting the outer and major rim are known in the eastern portion of the region as the Moosic Mountains and reach their highest elevation in the northeastern section. Southwestward they lose their range-like character and make up for the most part a rather broad upland with many hills and knolls standing above the general level. This particular portion of the mountains marks a coalescence with the somewhat dissected Pocono Plateau. In the southwestern section the higher elevations are known as the Wyoming Mountains and resume their ridge-like trend towards the west.

It is in the southwestern half of the region that the double ridge rim is particularly noticeable. There the inner rim is known as Wilkes-Barre Mountain, made up of the Pottsville formation. It usually lies several hundred feet below the summit levels of the outer rim, and continues westward several miles beyond the Susquehanna where it bends sharply back, continuing towards the northeast. The character of the double rim is best appreciated by noting the gorge-like character of the Susquehanna in the southwest. Here it is walled between two mountains, Shickshinny (Pocono formation) and the Pottsville ridge to the south.

DRAINAGE

The drainage features of the valley are in themselves very remarkable and are closely linked with the evolution of the landscape. Among the features which are apparent at first glance is the peculiar character of the main stream. The Susquehanna enters the valley from the north and almost immediately makes a sharp elbow bend towards the southwest. Then for a number of miles it flows over a wide alluvial fill which it has cut into a series of low terraces. It leaves the valley by turning west and cutting across the hard Pottsville formation. Again it turns southwest, flows in a narrow gorge cut in the Mauch Chunk shale, and leaves the syncline by making a sharp bend to the south. The Lackawanna River, the second major stream in the valley, enters in the extreme northeast and flows southwest about 30 miles until it enters the Susquehanna. Its course is not marked by any unusual features, for throughout it closely follows the pitching axis of the syncline.

The tributaries to the main stream, the Lackawanna-Susquehanna, might reasonably be expected to be as numerous on one side of the valley as on the other. In fact, however, streams large enough to merit names on a topographic map and which enter the valley from areas beyond by breaching the mountain rim, are far more numerous on the north and west side than on the south and east. These streams are listed below. It will be seen that while eleven streams have succeeded in breaching the double rim and have entered the valley on the north, but four have succeeded in doing the same thing on the south. Yet we know that the rainfall is substantially the same in distribution and amount throughout the area and the rimming mountains are made up of the same kind of rock.

STREAMS ENTERING THE VALLEY BY BREACHING THE RIM

North and West

Lackawanna River (above Forest City)
Fall Brook (Carbondale)
Rush Brook (Jermyn)
Olyphant Creek (Olyphant)
Leggetts Creek (Providence)
Susquehanna River (Pittston)
Abraham Creek (Wyoming)
Toby Creek (Luzerne)
Harvey Creek (W. Nanticoke)
Hunlock Creek (Hunlock Creek)
Shickshinny Creek (Shickshinny)

South and East

Roaring Brook (Scranton)
Stafford Meadow Brook (Scranton)
Spring Brook (Moosic)
Buttonwood Creek (Wilkes-Barre)

ALLUVIAL FEATURES

Scattered over the valley bottom and on the lower sides of the mountain are found accumulations of sand, gravel, clay and mixtures of all three in varying proportions. In places these deposits are thin but in others the bedrock is totally lost to sight under a thick burden of debris. These deposits are intimately related to great ice sheets which swept over the area in recent geological time, and constitute the detritus carried by the ice and by the streams discharging from it. The most recent of the great ice sheets reached its southern limit some miles southwest of the region under discussion.

THE BUILDING OF THE FOLDED APPALACHIANS

DEPOSITION OF THE SEDIMENTS

At the beginning of Paleozoic time the continent of North America presumably was a low-lying land mass, for the most part a broad flat platform standing slightly above the general level of the sea. Because of the low-lying nature of the continent and its general flatness throughout much of the Paleozoic era, the sea was able to encroach upon the land frequently and there leave numerous sedimentary deposits as a record of its various visitations.

The entire continent was by no means solely of this character. To the east and to the west of the present land borders of North America stood two great highland masses, Appalachia and Cascadia. Throughout the great Paleozoic era these highland masses suffered weathering and erosion, their slow destruction furnishing the tremendous quantities of sediments that were deposited in the seas along their borders. With the eastern land mass we are more immediately concerned, for the rocks which make up the mountains and valleys of northeastern and western Pennsylvania were derived from the detritus washed out of this ancient Appalachian highland. These were our first generation of Appalachian mountains, long since worn down so that even their very roots are covered today by the sands of the Atlantic Coastal plains. (See Figure 3.)

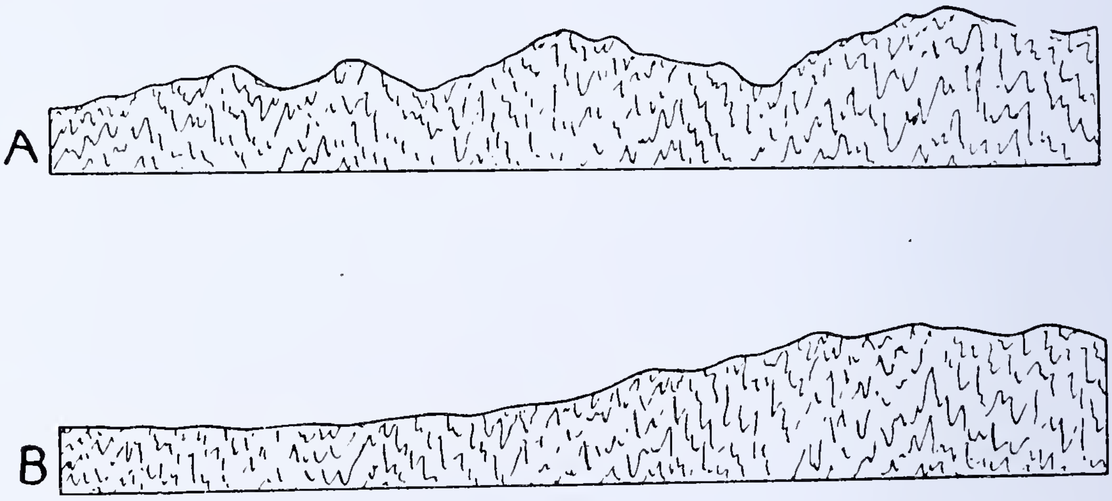


Figure 3. Ancient Appalachian Highlands.
A. Ancient mountains of complexly folded crystalline rocks.
B. Reduced by erosion.

Between Appalachia on the east and the broad flat platform of central North America existed a great troughlike basin—a geosyncline. This Appalachian geosyncline occupied portions of what are now Labrador, Quebec, Vermont, New York, Pennsylvania, New Jersey, West Virginia, Kentucky, Tennessee, Alabama and Mississippi, and opened on the north to the Atlantic Ocean and on the south to the Gulf of Mexico.

A slight rise of the sea or depression of the land resulted in flooding this trough so that throughout much of Paleozoic time it must have existed as a trough-like arm of the sea. Although it probably was never very deep, nevertheless into it from the land mass on the east poured great rivers with their accumulation of detritus, until it is estimated that a vertical thickness of 40,000 feet of limestone, sandstone and shale were deposited within it. These 40,000 feet of materials throughout their vast thickness show evidence of having been deposited in relatively shallow water, as proved by the coarseness of the sediment, ripple marks, fossils, coral reefs, etc. It is generally agreed that the great Appalachian trough subsided at intervals throughout Paleozoic time so that this great thickness of deposits could accumulate without the depth of the sea ever being very great. At the same time the ancient land mass to the east must necessarily have risen, not steadily, but at intervals so that it continued to serve as a source of sediments for the geosyncline (Figure 4).

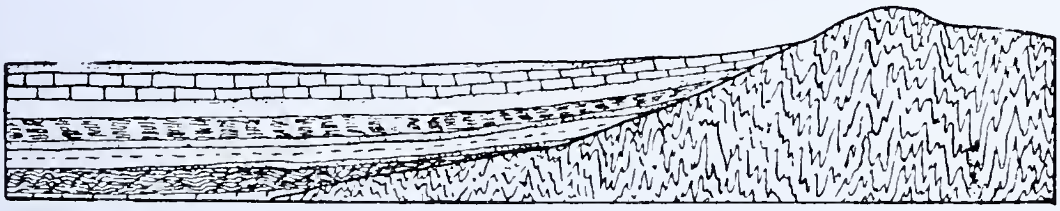


Figure 4. Deposition of sediments in the Appalachian geosyncline.

THE APPALACHIAN REVOLUTION

This seems to have been the general state of affairs throughout much of Paleozoic time: depression at intervals of the great trough with uplift of the land mass, constant wearing away of the land, filling of the basin. It is true there were one or more periods of disturbance, when the sediments already accumulated were crumpled. But relative quiet reigned throughout much of this immensely long era. Then towards the end of the Paleozoic the forces which had preserved the seeming balance between crest and trough either ceased to operate or were submerged by more powerful forces whose true cause is as yet unknown. Irresistible forces from the southeast increased until finally the continent began to buckle where the great Appalachian trough lay with its thick accumulation of sediments. In yielding the sediments were slowly yet surely arched, folded or fractured, and broken by great overthrusts, the latter movements sometimes carrying older beds of rock over those of younger age. Thus in place of a subsiding sea trough bordering the shore of the great interior sea, arose the second generation of Appalachian Mountains, the mighty folds which at the full stage of their growth and while still topographically young may well have been a lofty and extensive range rivalling the present Alps in height and majesty. This great mountain range extended at least from the region bordering the mouth of the St. Lawrence River on the north to Alabama on the south, and possibly much farther in either direction (Figure 5).

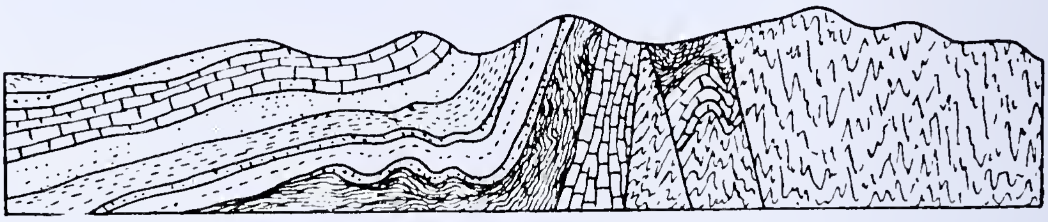


Figure 5. The Permian Appalachians.

Such a tremendous movement of the earth's crust culminating in the creation of a great mountain system where previously had been an arm of the sea, has well been termed a "Revolution." As a result of this great physical revolution virtually all of eastern North America was raised well above sea level. In Pennsylvania particularly the revolution produced arches and folds on such a grand scale as to lead geologists to believe that the crests of the Pennsylvania Appalachians must have stood 10,000 to 15,000 feet above sea level.

One may ask, are not the present Appalachian mountains, the long even-crested hard rock ridges, merely the remains of the Paleozoic Appalachians, only worn down nearer to sea level? They are made of the same sediments and structures, but they were brought into topographic relief by far different processes and at a very much later date in the history of the world as will be seen in the chapters which follow.

THE GREAT DENUDATION

CONSTANT CONFLICT OF UNLIKE FORCES

The surface features of the earth are the result of the operation and inter-action of a series of processes that are at work today and that have been actively at work through the long distant geologic past. Both on the surface and throughout its mass, the earth is a center of constant activity with resulting constant change. The forms which we see on the surface today are the present result of the continued operation of these processes. In general there are two great sets of processes, entirely unlike in character, in mode of operation and in result produced. One set of processes might be called *diastrophic,* working largely within the earth; the other might be called *surficial,* working largely on the exterior. Although these two great sets of processes operate in such widely different fashion, they are both so intimately concerned with modification of the earth surface forms that in any discussion involving evolution of the landscape it is quite impossible to treat them separately.

The diastrophic forces are the spectacular forces whose present operation is indicated to man by earthquakes, volcanic eruptions, etc. These are the great forces which slowly elevate or depress whole continents or portions of continents. They are the forces which elevate portions of the earth's crust into high ranges. They are known as *constructive forces.*

Opposed to the diastrophic forces is a second group of forces whose main source of energy is derived from the sun. Under various modified forms the sun's energy becomes an agent of change in the lithosphere, or earth crust. By setting the atmosphere in motion, creating winds; by aiding in the development of waves and ocean currents; by introducing moisture into the air and guiding its distribution to give us lakes and rivers; by inducing the decomposition and disintegration of rock; by determining where the moisture shall fall; by changes of temperature; by frost action, and in many other ways the surficial forces produce their effects on the earth's crust. The ultimate result of these external dynamic forces is to lower the level of the lithosphere to a spheroidal form by removing those parts that are too high and filling the parts that are too low. These complex forces may be grouped under the name *denudational forces.*

The diastrophic forces are tending to produce diversity of surface form: the denudational forces cooperating with gravity and utilizing air and water as agencies may temporarily increase this diversity, but ultimately they tend toward the reduction of irregularities.

Thus the evolution of surface features is seen to be a product of the inter-action of two groups of unlike forces—the result of the conflict being the land forms seen today.

THE LEVELING OF THE APPALACHIANS

During the latter part of the Paleozoic era diastrophic forces were so far superior to denudational forces as to raise up the mighty Folded Appalachians, as indicated previously. It must be remembered, however, that scarcely were the first anticlinal folds raised ever so slightly before the forces of denudation began their ceaseless attack upon the new land mass. For a long time, no doubt, the diastrophic forces continued triumphant, until finally they may have elevated the Appalachians to an Alp-like grandeur. Yet all the time were the unceasing forces of denudation at work. Not so sensational nor so rapid in their mode of operation as the diastrophic forces, nevertheless by almost imperceptibly slow degrees, they kept gnawing at the majestic mountains. So long as the diastrophic forces were powerfully active the denudational forces must have seemed pitifully inadequate to combat them. However, while diastrophic forces appear to be largely rhythmic in their outburst, the terrestrial forces are constantly at work. For the most part during the long periods of Mesozoic time, particularly the Jurassic and Cretaceous, diastrophism on a great scale was here virtually non-existent, leaving the field clear to the less imposing denudational forces to carry on their work. In any event the dominant processes during the Mesozoic Era were denudational. The ultimate accomplishment of the denudational processes was the production of a general lowland, a great wide area of faint relief with very gently sloping divides between the streams.

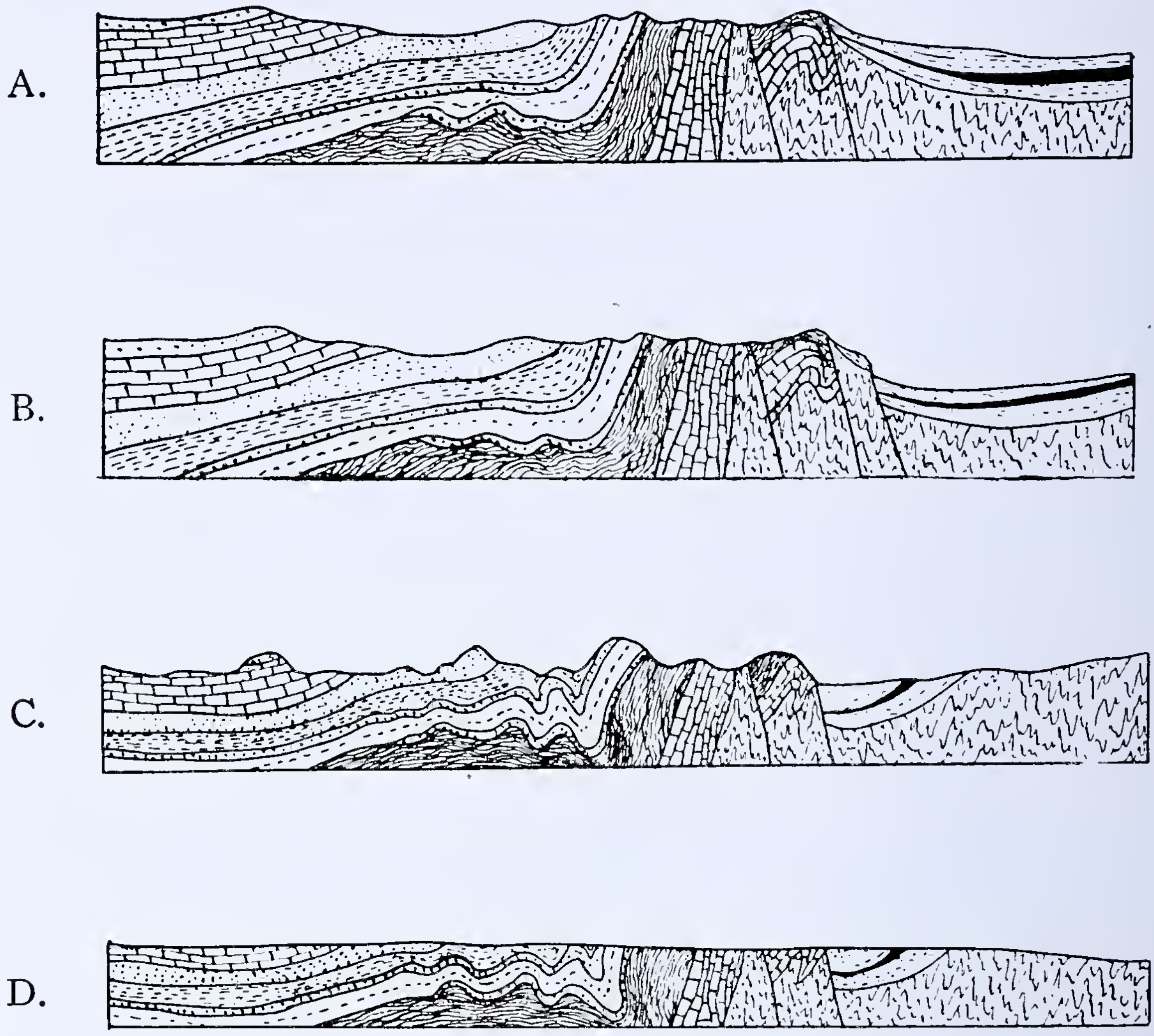


Figure 6. Reduction of the Appalachian mountains to a peneplane. (Modified after Douglas Johnson.)

A. Appalachians greatly reduced by erosion. Deposition of Triassic sediments on the east, with intrusive and extrusive trap sheets.
B. Infaulting of the Triassic sediments.
C. Rejuvenated Appalachians in post-Newark time.
D. The Fall Zone (Cretaceous) peneplane.

Where once stood the mighty Appalachians there now remained nothing save a nearly featureless plain of denudation—a peneplane. (See Figure 6.)

THE MARINE INVASION

Presumably during one of the very long still-stands of the earth, one of the periods when diastrophism probably ceased its activity, this great plain of denudation was completed. Early in the Cretaceous period, however, there was enough subsidence or warping of the seaward margin to allow the sea to encroach upon and cover with sediments a considerable portion of the area. Certainly very little downwarping of the surface was necessary in order to produce proper conditions for this sedimentation, for as previously noted the eastern margin of the continent was already low-lying as a result of the Jura-Cretaceous denudation.

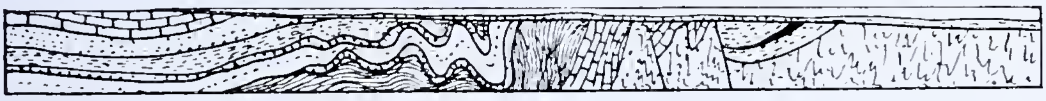


Figure 7. Encroachment of Cretaceous sea and deposition of coastal plain beds. (Modified after Douglas Johnson.)

When one considers the Atlantic border conditions during the Cretaceous period it is not difficult to believe that transgression of the sea over wide areas might easily take place. The broad low-lying peneplane sloping very gently seawards would present a nearly featureless floor. Gentle depression of the land would flood many thousands of square miles of the border country. When finally the sea withdrew from the erstwhile peneplane it would leave thereon a mantle of sediments which must completely obliterate all preexisting drainage (Figure 7). That such a sedimentary mantle did cover part of the planed-down Appalachians admits of no doubt. For reasons set forth elsewhere in this report the author adopts the Johnsonian hypothesis that the sediments extended inland to and beyond the region here discussed.

THE NEW DENUDATION

THE SCHOOLEY PERIOD

Uplift of the land and withdrawal of the sea must necessarily have initiated a new drainage and a new erosional cycle. Inasmuch as the new surface was that of a coastal plain the drainage evolved on that surface must have been similar to the type of drainage which we see today on the present Atlantic and Gulf Coastal Plain. It is believed that the present major drainage as seen in the Wyoming-Lackawanna area is in part due to inheritance of ancient courses originally formed on this coastal plain.

In the Wyoming-Lackawanna region there are three very important changes in direction of the Susquehanna drainage, so important as to require serious consideration as to their possible cause.

The first peculiarity of the drainage is the great bend which the Susquehanna makes immediately after entering the valley. Is it not peculiar that a great stream like the North Branch of the Susquehanna should follow such a direct line toward the southeast of perhaps 150 miles, break through the hard northeastern rim of the valley, and then find itself turned toward the southwest in a 90° bend at Pittston? Why should the river have turned so suddenly at this point? Why does it not continue toward the southeast and break through the southeastern wall of the valley as it does through the northwestern?

Then, as the course of the Susquehanna is followed down the valley, one finds the river has achieved a seeming miracle. Instead of continuing within the softer rocks of the coal measures lying in the great syncline, the river turns abruptly northwest at Nanticoke and crosses the resistant Pottsville conglomerate. But no sooner has it crossed this hard layer than it seems to reconsider its future course of action, and instead of continuing to the west and cutting through the resistant Pocono ridge, it swings off once more toward the southwest and follows a narrow gorge between the twin mountain ridges for about nine miles. The questions to be answered here are obvious. Why did the river turn toward the northwest, cross only one hard ridge and avoid the second?

The third problem deals with the very unusual course of the river as it leaves the syncline. Here the river performs a still more remarkable feat. At Shickshinny it makes a great 115° bend toward the south and crosses three resistant ridges in rapid succession, producing three watergaps. The river here has to recross the ridge which it previously crossed upstream. Instead of lessening its work by its curious bends, it has more than doubled it.

DRAINAGE CHANGES

The North Branch Susquehanna is believed to have extended southeastwards across the plateau now known as the Poconos, its lower course following the general route now taken by the Delaware River from Easton to Trenton (E to T on Figure 8). Another stream, the Little Schuylkill, flowed southwards from the region west of the North Branch, continuing to the general region of Port Carbon where it met the main Schuylkill flowing southeastwards. Both of these streams must have developed branches on the coastal plain. Such a branch extended eastward from the Schuylkill or westward from the ancient Susquehanna, possibly both. The relations of these streams during the early part of the Schooley cycle are shown on Figure 8.

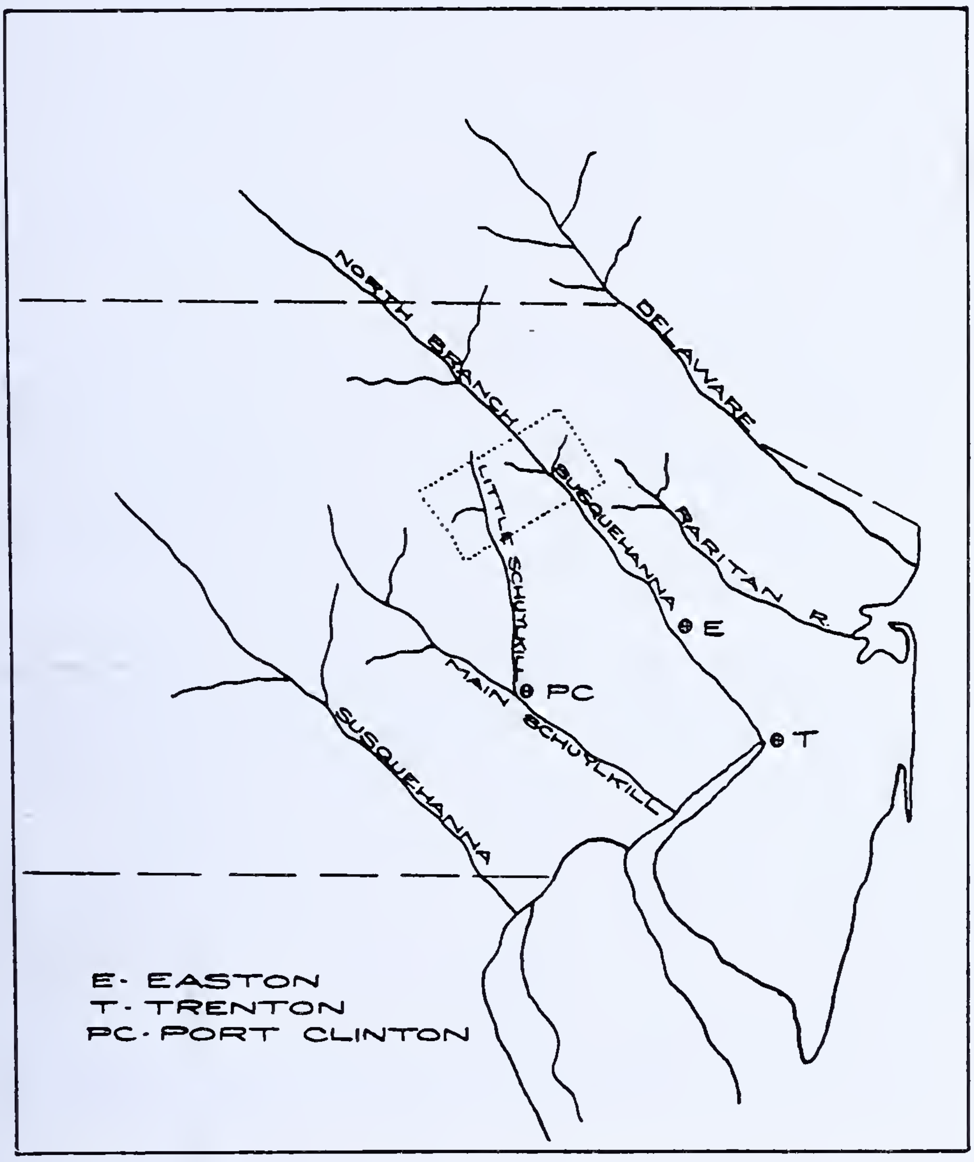


Figure 8. General type of drainage as developed in early stage on the coastal plain.

Both the southward-flowing Little Schuylkill and the North Branch Susquehanna ultimately encountered severe obstacles in their courses. After cutting through the mantle of coastal plain sediments they must have found considerable areas of hard rock beneath them. So long as all the streams in the region were of about the same volume and encountered the same obstacles, little in the way of stream diversion happened. Apparently a stream farther to the west, the present Susquehanna below its junction with the North Branch, either found the fewest obstacles or had such a great volume as to enable it to lower its course more rapidly than did the other master streams. As a result it began to rob them of their headwaters by capturing first their lateral branches, then their headwaters. The headwaters of the Schuylkill River were cut off by this western stream a few miles to the south of the syncline. The former southward course of the Little Schuylkill was disrupted and the augmented stream continued to cut eastward. Somewhere in the western part of the valley the growing western Susquehanna tapped the waters of the ancient North Susquehanna and turned them westward. The remarkable bend of the present Susquehanna as it enters the valley thus represents the "elbow" or point at which the North Branch Susquehanna departs from its former southeastward course. The peculiar northwest bend of the Susquehanna downstream is a course probably inherited from the old coastal plain, and the bend at the west end of the valley represents the former course of the Little Schuylkill as it flowed southward. These three important changes in the direction of the present North Branch Susquehanna are thus explained on the basis of superposition of earlier drainage from a coastal plain cover, followed by stream capture during the ensuing Schooley cycle of erosion.

Other changes of considerable note seem likely to have taken place in the Lackawanna portion of the region during the Schooley cycle. The ancient Raritan may have had its headwaters on the coastal plain in the region northwest of Scranton. During the Schooley period development of drainage eastward from the Susquehanna probably captured the headwaters of the Raritan River somewhere in the region and turned the drainage into the Lackawanna Valley which must have been taking form at that time. The ancient transverse Raritan is probably represented by a portion of Leggetts Creek, on the north side of the valley and by Roaring Brook on the south.

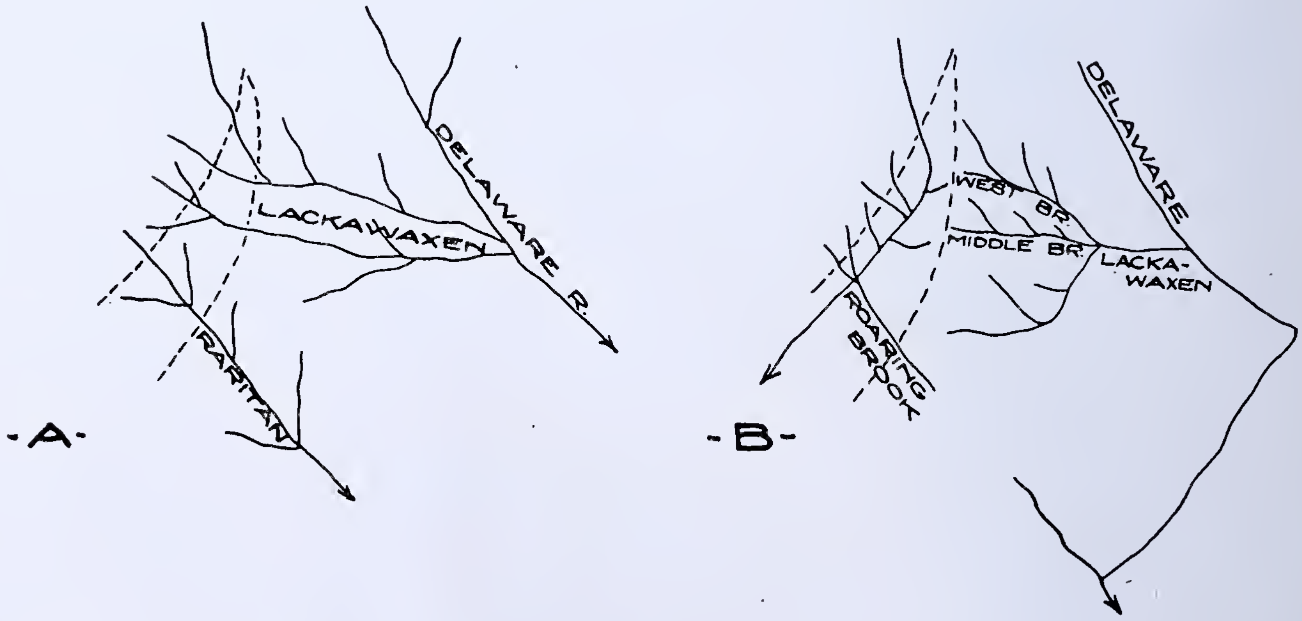


Figure 9. Presumable ancient and present upper Raritan and Lackawaxen drainage.

Ancient Delaware drainage likewise appears to have been represented in the area. The Middle Branch and West Branch of Lackawaxen River may have headed northwest of the valley. The presumable courses followed by these streams are indicated in Figure 9 These streams must have been diverted from their old course in much the same manner as the headwaters of the ancient Raritan and probably succumbed to the same capturing stream.

Probably most of the major adjustments in the drainage of eastern Pennsylvania took place during the Schooley erosional cycle, so that the general courses of the major streams as we see them today were developed during that erosional period.

Aside from the drainage adjustments the streams which flowed over the erstwhile coastal plain attacked the underlying hard bedrock with considerable vigor. As erosion progressed during the early Tertiary period the relief of eastern Pennsylvania must have attained an aspect somewhat similar to its present condition. Ultimately, however, the region was for a second time reduced through erosion to a gently undulating erosional surface known as the Schooley peneplane (Figure 10).

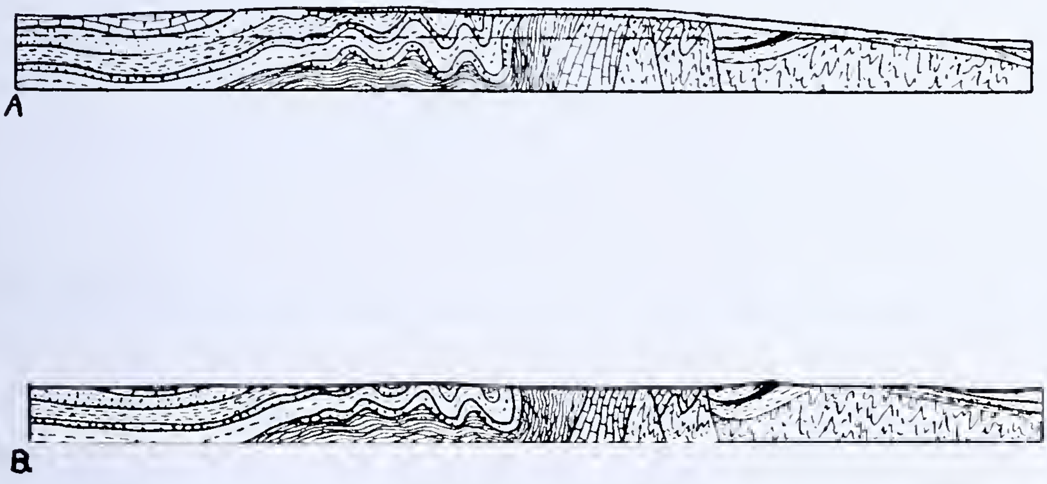


Figure 10. A. Arching of Fall Zone peneplane and its coastal plain cover. Regional superposition of southwestward-flowing streams. (Modified after Douglas Johnson.)

B. The Schooley (Tertiary) peneplane. (Modified after Douglas Johnson.)

THE HARRISBURG CYCLE

The Schooley peneplane, with the major drainage much as is seen today, was uplifted later in the Tertiary period (Figure 11). This uplift was probably far inferior in magnitude to the uplift of the Cretaceous peneplane with its coastal plain cover. It initiated a new erosional cycle so that the nearly level Schooley surface was subjected to denudational processes. The new cycle is known as the Harrisburg cycle, after the city located on remnants of a partial peneplane produced during this period. In the Harrisburg cycle insufficient time was given the denudational process to reduce the entire Schooley surface to a new level. In general the softer and more easily eroded rocks alone were worn down. The harder rocks stand out today as remnants of the older erosion surface. Thus the mountains which rim the Wyoming-Lackawanna Valley, the Pocono Plateau, and the higher ridge crests in the anthracite regions are remnants of the Schooley peneplane.

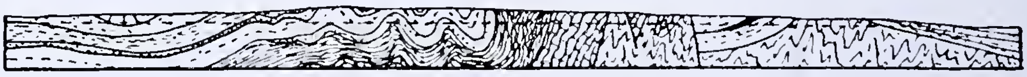


Figure 11. Arching of the Schooley peneplane. (Modified after Douglas Johnson.)

At the conclusion of the Harrisburg cycle the region presented a far more uniform picture than at present. Over much of eastern Pennsylvania extended a gently rolling peneplane, interrupted, however, by ridges and plateaus of hard rock remnants of the Schooley surface (Figure 12).

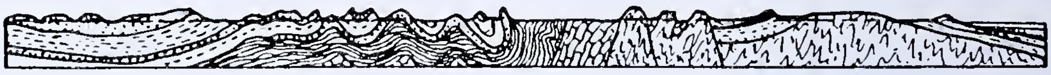


Figure 12. Dissection of Schooley peneplane; development of Harrisburg peneplane on belts of non-resistant rock. (Modified after Douglas Johnson.)

THE SOMERVILLE CYCLE

Before it could completely reduce the entire area to a peneplane the Harrisburg cycle was interrupted by another uplift. This probably amounted to a maximum of 300-400 feet, but was sufficient to start the streams cutting to a new lower level (Figure 13). Remnants of the Harrisburg level are found in the hilly, rolling country northeast of the Wyoming-Lackawanna region. Other areas in which this peneplane is represented are in the Honesdale region, northeast of the Poconos, and in the wide valley drained by the Wapwallopen and Little Wapwallopen Creeks in the region southwest of the Poconos. In general the hilltops in these three areas reach an accordance in elevation, and are flat or gently sloping. In the valley itself there may be a few very minor remnants of the Harrisburg level, but almost all of this surface has long since been removed by erosion.

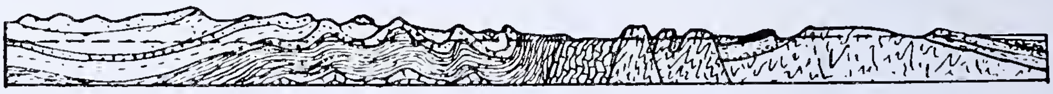


Figure 13. Uplift and dissection of Harrisburg peneplane and development by erosion of the Somerville on belts of weaker rocks. (Modified after Douglas Johnson.)

The general effect of the post-Harrisburg uplift was the production of rather narrow valleys cut below the Harrisburg surface. But in certain parts of the Appalachian region broader lowlands were produced. For the most part this third level, known as the Somerville, is extremely limited in extent. It is represented in the southwestern section of the region under discussion by the bench paralleling the north bank of the Susquehanna between Mifflinville and Bloomsburg. Within the valley, particularly in the Nanticoke-Wilkes-Barre section, there are a considerable number of hills which probably represent the Somerville erosional surface.

The development of the Somerville surface was interrupted by an uplift in recent times amounting to 200-250 feet (Figure 14). As a result many of the streams in the region flow today in deep narrow stream valleys cut considerably below the Somerville, Harrisburg, and Schooley peneplane surfaces.

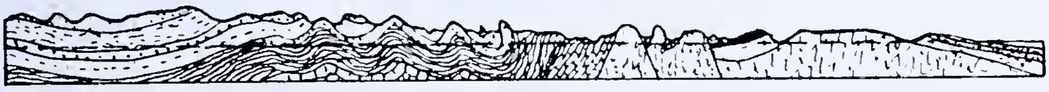


Figure 14. Uplift and dissection of Somerville peneplane to give present conditions. (Modified after Douglas Johnson.)

At Pond Hill station and Wapwallopen the Harrisburg erosional surface ends in a bluff at the river's edge. Here the river has cut from 550-600 feet below the Harrisburg level.

The landscape as seen at the conclusion of Tertiary time, following the uplift of the Somerville and all older surfaces, would be essentially what we should see today, had it not been that at the conclusion of Tertiary time a new geologic chapter was inaugurated by the coming of great sheets of ice which further changed the pre-existing landscape.

THE TWIN RIM AND ITS INTERPRETATION

The double mountain or twin rim surrounding the western portion of the Wyoming basin owes its origin to the fact that in post-Schooley cycles of erosion denudational processes have excavated lowlands of considerable length and depth in the Mauch Chunk red shale. This shale lies between the Pocono sandstone which is stratigraphically beneath it, and the Pottsville conglomerate and sandstone above it. Because these two formations are very much more resistant to denudational processes than the Mauch Chunk, the lowland or valley is produced in the latter. The valleys in the Mauch Chunk formation in this area are not very wide for the dips of the formations in the west end of the mountain are well over 30 degrees, so that unless the Mauch Chunk were of great thickness we should not expect a valley of great width. Nevertheless we might expect to find a valley of some width in the Mauch Chunk formation developed about the entire Wyoming basin, everywhere separating the two ridges of a double mountain rim.

Eastward along the mountains rimming the valley north and south of Wilkes-Barre, however, the Mauch Chunk valley and the double rim appear to die out. Here and there slight ravining in the crest of the ridges flanking the valley suggests a softer formation which is undergoing an etching process.

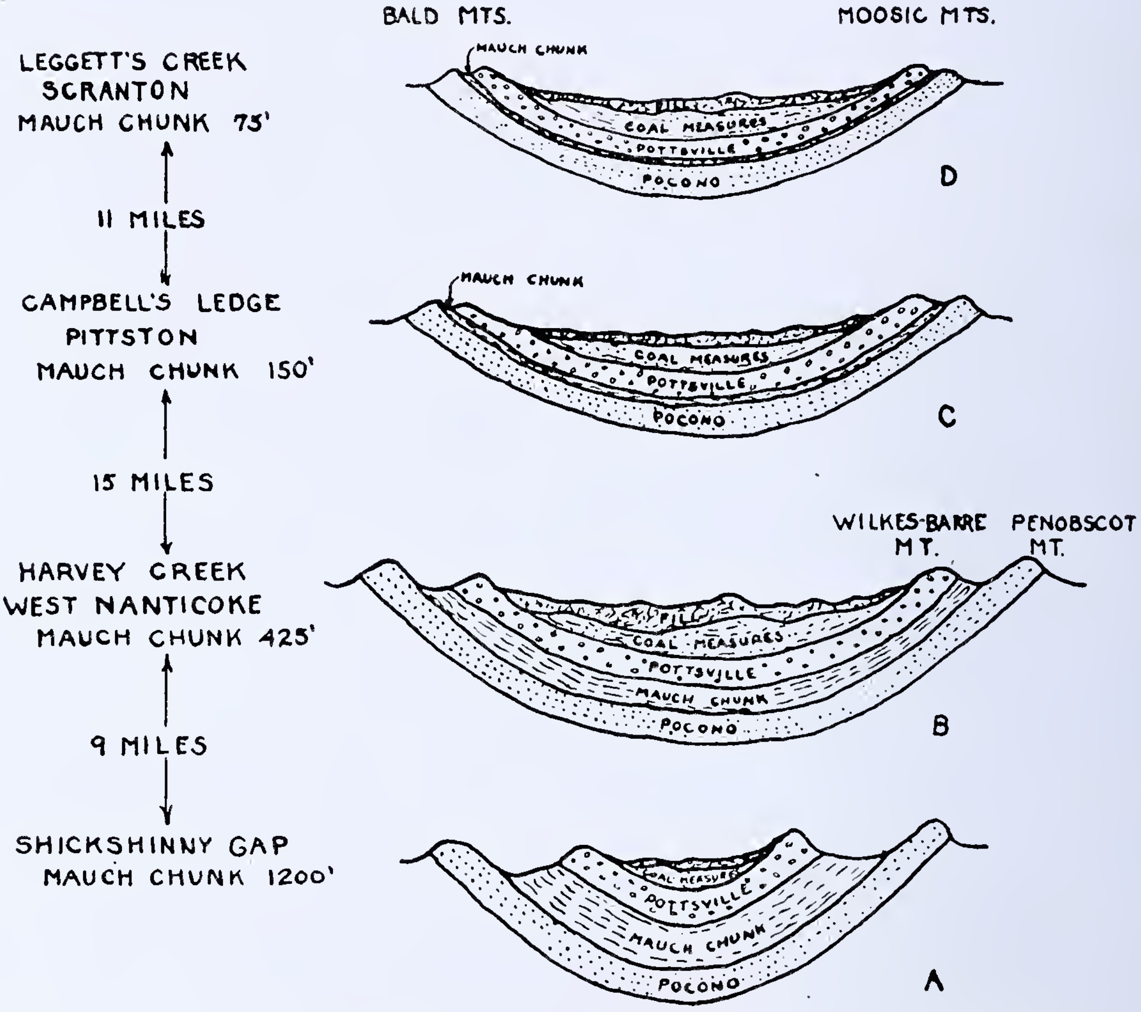


Figure 15. Generalized sections showing thinning of Mauch Chunk eastward with loss of twin rim.

The loss of the double rim in the eastward portion of the area is an excellent illustration of the relation existing between topography or surface form and the underlying geology. The twin rim ceases to develop because the formation which normally makes the lowland has thinned out toward the east. Thus at the west end where the Mauch Chunk formation has been carefully measured the formation has a vertical thickness of 1200 feet and is made up mostly of fairly soft red shales. This is shown on Figure 15 as A. About nine miles east of A the Mauch Chunk formation is only 425 feet thick (section B) and as a result the valley tends to narrow. Fourteen miles farther northeast, where the Susquehanna breaks through the mountains into the valley, the Mauch Chunk has diminished to a thickness of 150 feet (section C). In a distance of 11 miles farther northeast the Mauch Chunk has dwindled until it is not over 75 feet thick (Section D). In addition the soft shaly character and the red color of the Mauch Chunk have disappeared and the formation has taken on the lithologic character of the Pocono formation which underlies it. Here the formation is gray or buff in color and sandy or pebbly in texture. As a result of the thinning of the Mauch Chunk and its change in lithologic character toward the northeast the twin rim has failed to develop.

THE ADVENT OF THE ICE

During the Glacial epoch much of northeastern Pennsylvania suffered from the effects of a series of great continental ice sheets which advanced and retreated throughout the area (Figure 16). The last of these ice sheets, the Wisconsin, must have lingered for thousands of years in the region, reaching its southern limits some fifteen or twenty miles southwest of Wilkes-Barre. The extent of the earlier ice invasions and the work accomplished by them in this region is not very well known, for the last ice sheet largely obliterated or modified the effects of the earlier sheets. Much of what may appear as the work of the Wisconsin ice may well have been accomplished by one or more of the earlier sheets. The line limiting the southern extent of the ice follows a general northwest-southeast trend across this region but has many local irregularities. It is often marked by ridges

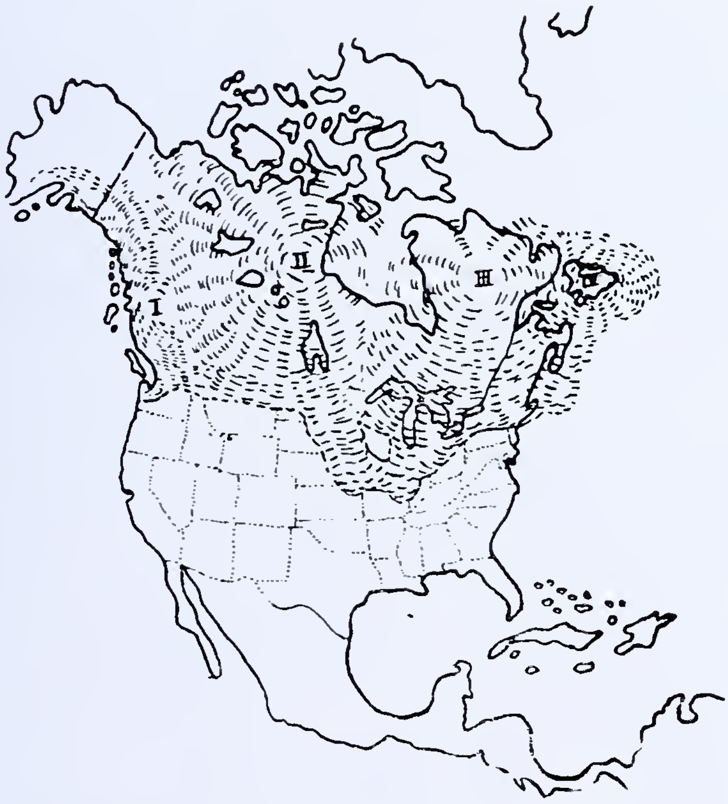


Figure 16. Sketch map of North America showing centers of ice accumulation and area covered by ice during the Pleistocene. (After Grabau.)

and heaps of sand, gravel, and boulders accumulated at the terminus of the glacier. To the north the ground is covered to a greater or lesser extent with accumulations of debris left when the ice sheet dissipated. On steep hillsides much of this glacial debris has been washed away, but along the lower mountain slopes and in the valley bottoms extensive deposits are still found. South of the edge of the terminal moraine, the preglacial topography is barren of such accumulations.

At the time of its greatest development the ice sheet is believed to have been several thousand feet thick and to have moved slowly but surely southward. In the Wyoming-Lackawanna region the ice must have been sufficiently thick to fill the valley and cross the mountains to the south, as is shown by the striæ or scratches on those mountains. The surrounding mountains and the valley itself then had much the same form as at present, the ice sheet merely modifying minor features in the area.

The ice sheet changed the topography existing prior to the coming of the ice in two ways. The great thickness of ice, moving slowly southward, exerted a grinding, gouging, plucking action on the rocks over which it passed. This erosive action appears to have resulted in lowering the general surface level by a few feet only; but in certain localities where the ice moved parallel to the valley trend it seems to have accomplished much local deepening. A considerable portion of the Wyoming Valley seems to have been overdeepened through the work of the ice. Much of this overdeepened valley has since been filled in, resulting in the Buried Valley of the Susquehanna River.

During the passage of the ice over the area and in its final waning stages certain depositional features further modified the preglacial landscape. The ice picked up considerable local material, and ultimately upon melting dropped it. Streams of melt-water reduced much of the debris to sand, rounded gravel, and boulders. The ultimate deposition of this material resulted in various accumulations within the area. That deposited by streams marginal to the ice in rudely stratified form is seen today as kames and terraces. Other material deposited directly from the ice with little or no sorting or stratification is distributed unevenly throughout the region. This "till" is sufficiently thick in places to give certain irregular depositional forms. The depositional forms, stratified and unstratified, are discussed below.

DEPOSITIONAL FEATURES

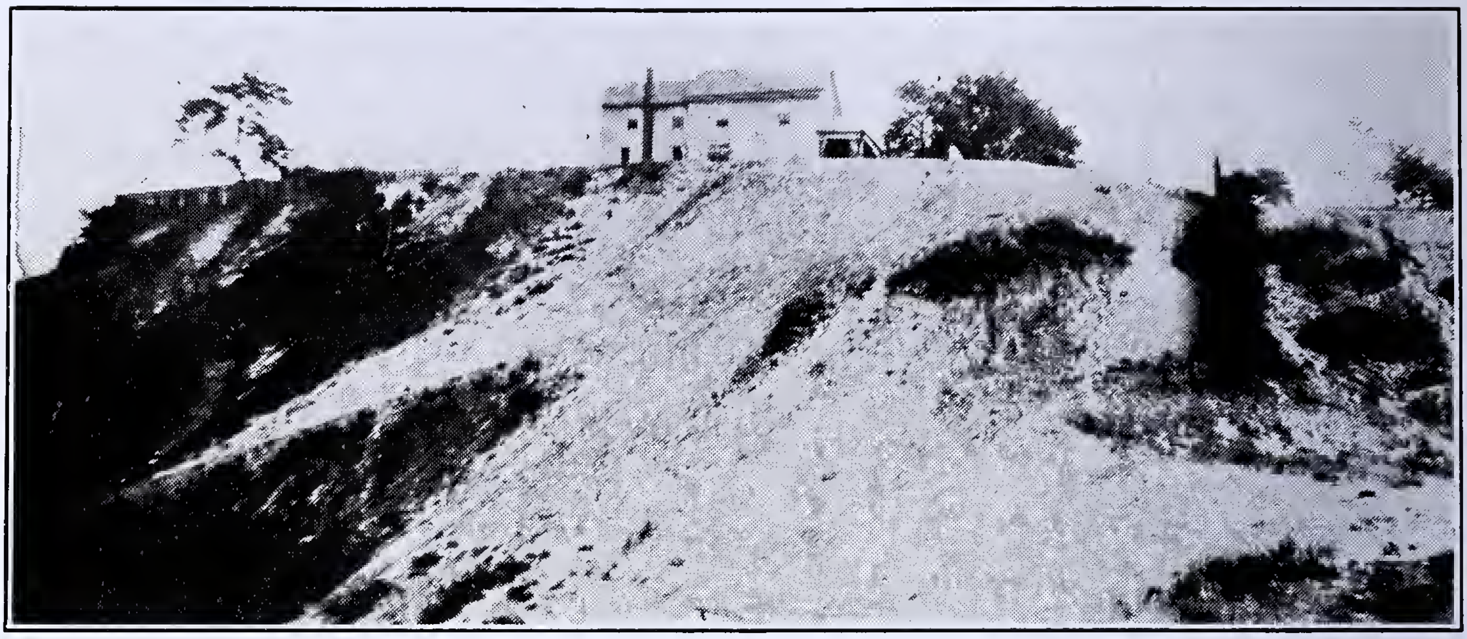
Deposits of Stratified Drift—Terrace and Kames

Much of the stratified material is arranged in high terraces occurring at intervals along the mountain sides in the southwestern two-thirds of the valley (Plate 1—A, B). These deposits were probably laid down in much the same form as they appear today. When the glacial ice was melting and filled only a portion of the valley, streams carrying considerable debris flowed between the ice and the valley walls. Other streams down the mountain sides removed much of the till covering the slopes, adding their debris to the current running lengthwise along the valley. Still other streams coming from the ice itself undoubtedly added their burden to the deposits. The result, as indicated in the diagram (Figure 46) was a deposit of stratified materials usually of complex structure. Terraces built up in this fashion are called kame terraces.

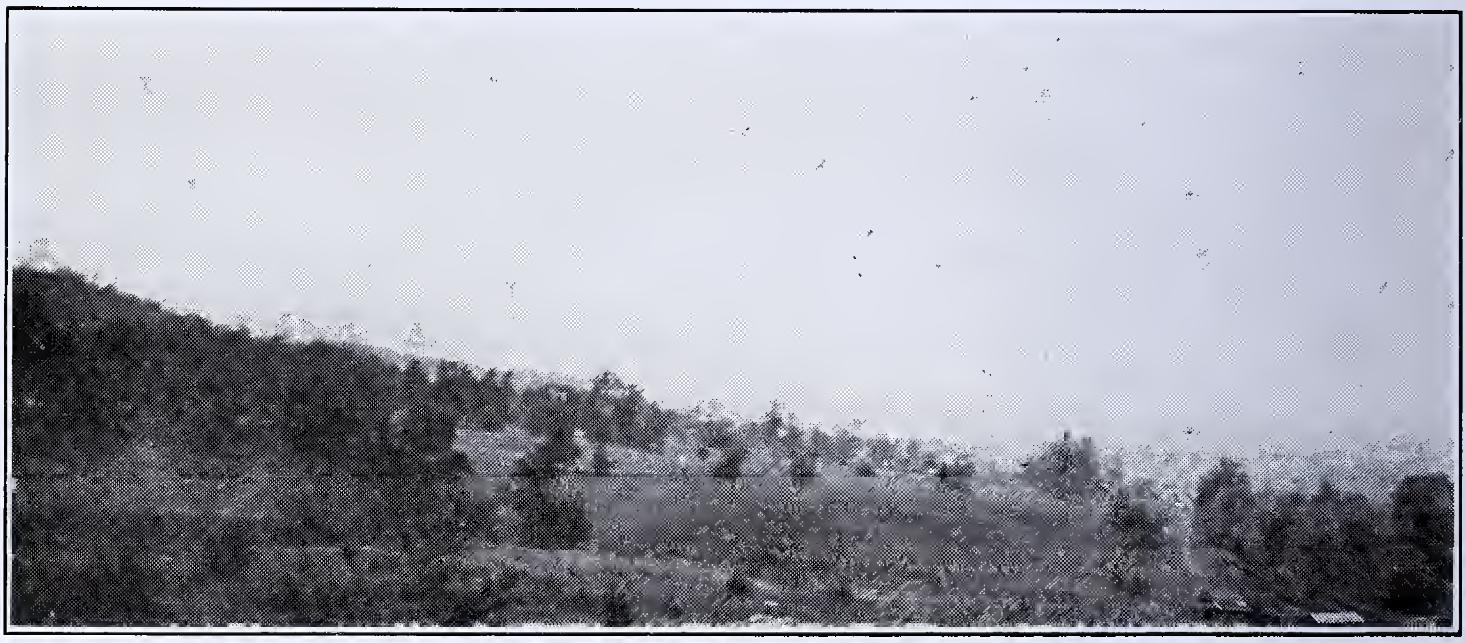
Where streams emerging from the ice built irregular hills or rudely stratified drift along the decaying ice margin, we have kames or kame moraines. They often are low rounded hills with gentle undrained depressions or kettle holes between them. Kame deposits are best shown on the north side of the valley between Scranton and Peckville and may be seen along the main highway over much of the route. Kame deposits also occur at Alden, a quarter of a mile northeast of the Alden store (Plate 1, C), and along the main highway between Parsons and Miners Mills, at the Fox Hills golf course at West Pittston and in the lower Lackawanna Valley in the Avoca, Old Forge, Duryea region.

Deposits of Unstratified Drift

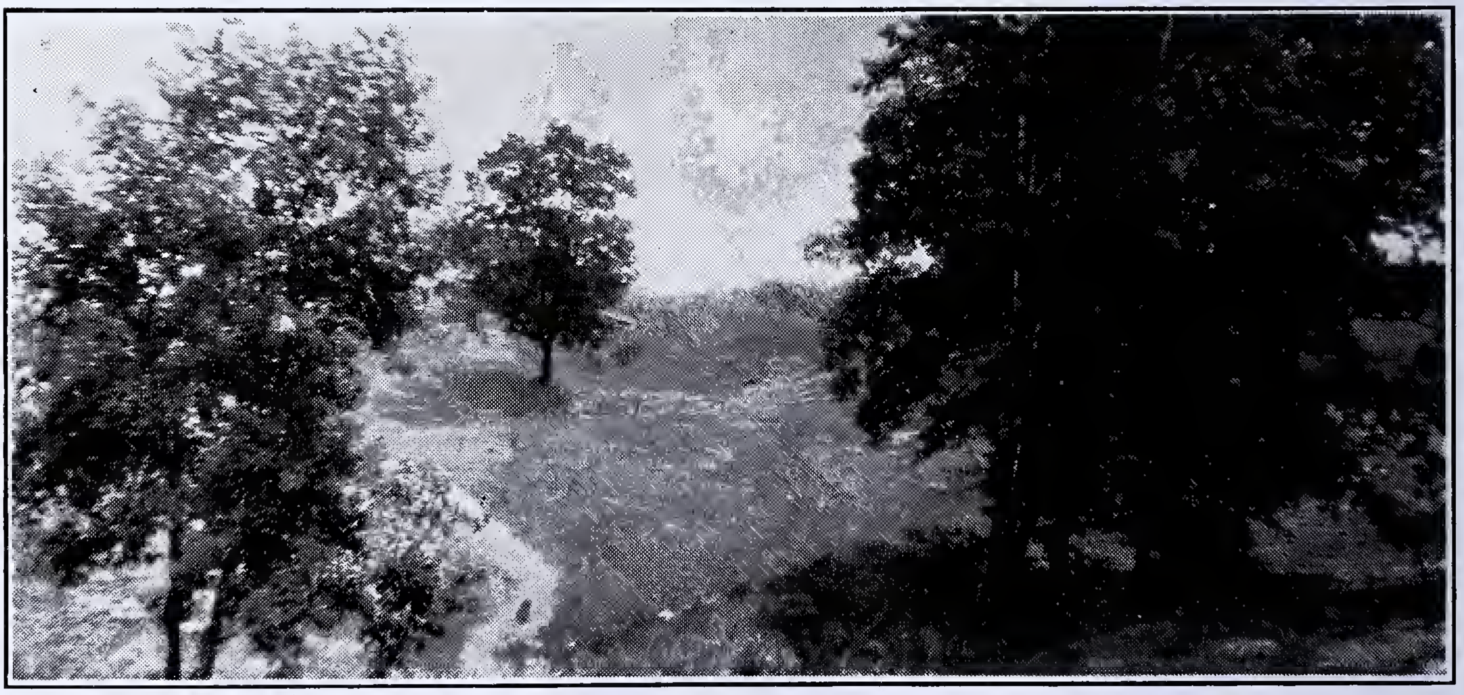
No doubt much of the northern anthracite field was covered with a sheet of unstratified drift or till deposited by the ice of the Glacial epoch. Subsequent erosion has removed much of the till and in certain areas the drift has been worked over by streams and redeposited in stratified form. The glacial till consists of a heterogeneous mass of sand and gravel with clay and boulders mixed in locally. In general the amount of clay is small, sand forming more than 50 percent of the material. The till probably averages 15 to 20 feet in thickness, but may be merely a thin veneer, or occasionally where it has filled depressions it may be 50 to 100 feet thick. Some of the thickest masses lie along the lower slopes of the mountains on the northwest side of the valley. Till deposits of considerable thickness and extent occur on both sides of the valley above Carbondale. An extensive area lies north and west of Peckville and along the lower hillside northwest



A. High terrace at Pittston, Pa. View from Laurel Line Station.



B. Terrace southwest of Alden, Pa. Upper part is made up of fan deposits and slope wash; lower part near terrace front exhibits delta structure.



C. Typical kame topography southeast of Alden, Pa.

of Blakely and Dickson City. Very extensive till deposits occur northwest of Scranton, in and to the north of Keyser Creek Valley. In Ascension Brook valley and flanking the hillside above Old Forge and Duryea there are thick deposits. Between West Pittston and Luzerne the high terraces of stratified drift grade into a heterogeneous till sheet on the lower mountain side. Along the foot of the mountain north of Larksville and Plymouth there are thick deposits of unstratified drift.

EROSIONAL FEATURES

The Archbald Potholes

Among the interesting geologic features of the Wyoming-Lackawanna region are the large potholes in the vicinity of Archbald. Early in February, 1884, miners opening a chamber from an airway encountered a mass of rounded stones weighing from one to six pounds each. This mass of cobbles rested like a barrier across the face of the workings from within a foot of the bottom of the coal bed up to the roof above the coal. When the miners had worked around it, leaving

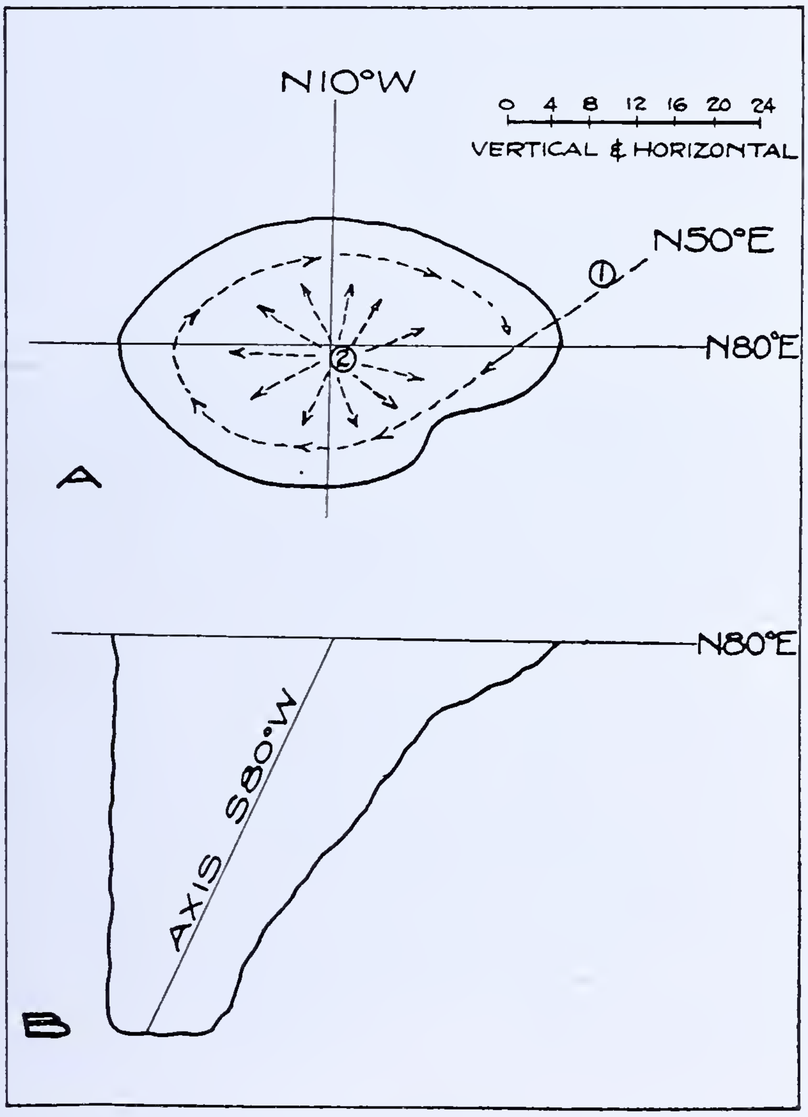


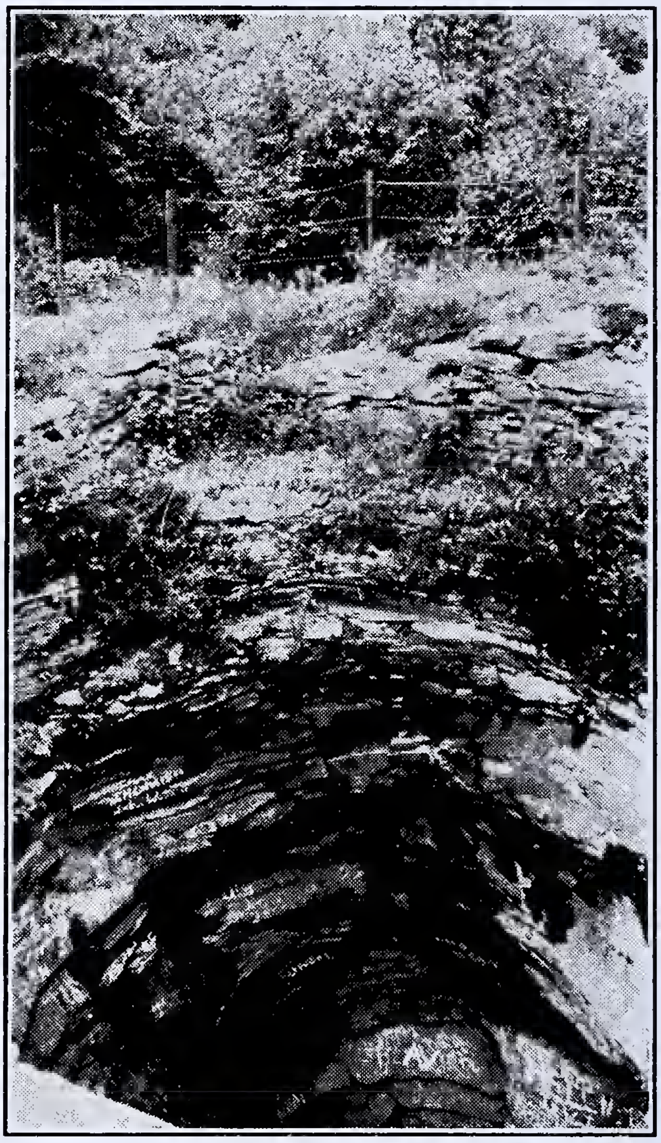
Figure 17. A. Surface outline of Archbald pothole.
B. Vertical section of pothole along plane N 80°E; and axis of inclination of pothole.

an oval pillar of rounded stones they began to remove the pillar and discovered it continued through the rock to the surface, a distance of about 40 feet.

A year or so later miners working about 1000 feet northeast of this pothole discovered a second in much the same manner as the first. The first pothole was subsequently cleaned out and used as an air shaft for ventilating the mines. The second was never cleaned out, hence its dimensions are known only approximately.

The excavated pothole is 38 feet deep. Its greatest diameter on the surface is 42 feet in a direction N 80° E, and the shortest diameter across the top of the hole is 24 feet. The axis of the hole is not vertical but inclined slightly in a direction S 80° W. The diameter of the hole narrows from top to bottom so that at the bottom it is less than 14 feet wide (east and west), and less than 17 feet long. (See Figure 17. Plate 2, A.)

PLATE 2

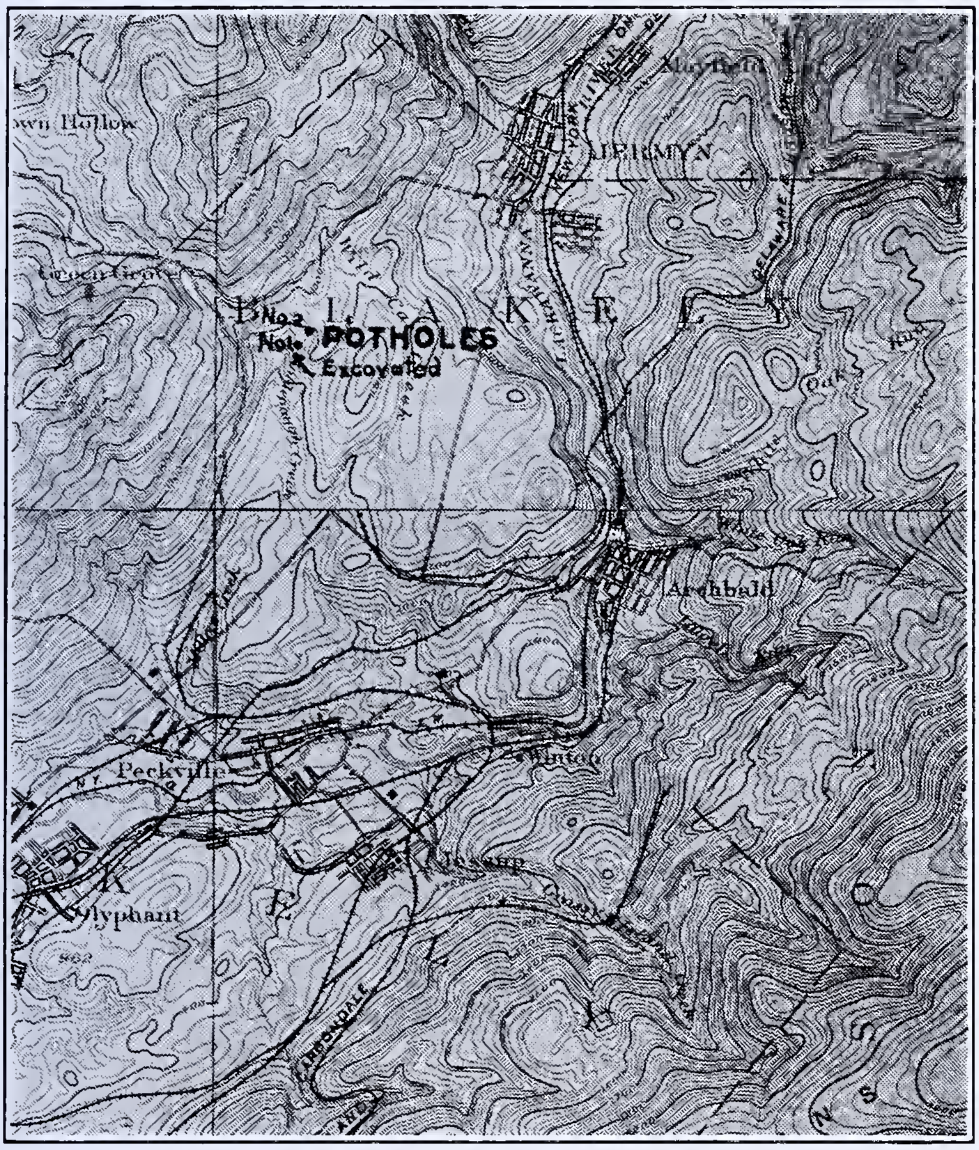


A. Upper portion of the Archbald pothole. (Photograph by Dr. George H. Ashley.)

The hole is cut in "slate," sandy shale, and the Archbald coal bed. Most of the cutting was done in the "slate" so that much of the rounded surface of the rock is still nicely polished, although in part exfoliation is stripping off the rock in thin layers. When the hole was first discovered geologists of the Pennsylvania Second Geological Survey examined the material taken from it and concluded that it came from formations stratigraphically above the Pocono, some of the material evdiently being formed from the rock and coal in which the hole was cut. Rounded pebbles of coal 5 inches in diameter evidently had been cut from the coal bed itself.

The second pothole, about 1000 feet northeast of the first, and occupying the same little pocket valley in which the first is located, is assumed to be about 50 feet in depth and of slightly greater diameter than the first.

PLATE 2



B. Topographic map showing location of the Archbald pothole.

While it is believed that the potholes have been formed at the bottom of a waterfall, the present topographic conditions in the region preclude the possibility of the potholes originating by water falling over any portion of the present surface. In the little valley in which the potholes are located there is no semblance of a cliff or steep slope over which the water might fall to produce a pothole. The present streams in the immediate area are very small and certainly unable to account for the production of potholes of this size even if given an obstruction over which the waters might tumble (Plate 2, B).

The most reasonable explanation for the mode of origin of the potholes appears to be that they are the result of excavation by glacial streams. Water in considerable volume flowed along the base of the ice sheet during the final stages of its dissipation. Other streams flowing on the ice, following well-defined paths leading from the Jermyn district toward Blakely, were interrupted by crevasses. Where the supra-glacial streams tumbled through a considerable vertical distance potholes of this size might well be developed. With the addition of strong subglacial streams meeting the waterfall at an angle, and with the slate and sandstone surface of impact dipping a few degrees, the potholes might be cut out in a much shorter time than if only the one stream were present and the rock structure less favorable.

The buried valley of the Susquehanna

The broad flat plain over which the Susquehanna River at present takes its course in the Wyoming Valley conceals a great depression in the bedrock surface. Nearly everywhere below the center of the flood plain this depression is over 100 feet deep, and in places exceeds 300 feet. Certainly the present surface of the valley gives little indication that an ancient deep valley exists beneath it.

Coal operators and miners have long known of the existence of the ancient buried valley of the Susquehanna. Miners working along coal beds underground have occasionally come into contact with the deposits filling the ancient depression. Realization of the danger of cave-ins, several of which have proved fatal, led to early study of the configuration of the rock floor of the valley. The coal-mining companies have bored more than 2000 test holes for the purpose and these give perhaps the most adequate data for any buried valley ever studied.

The buried valley of the Susquehanna consists of a major depression made up of a series of elongated basins which are terminated by rock at both ends. The valley does not have a continuous downgrade, for the deeper sub-basins decrease in depth down stream. The channels were excavated in the various sandstones, shales, slates, and coal beds of the rocks known as the coal measures. In the northeastern section near Coxton discontinuous channels more than 200 feet deep have been found. In the southwestern area near Nanticoke where the river at present leaves the valley the average depth of the old channel is 180 feet. The deepest part of the buried channel is directly south of Plymouth where bore-holes have found the rock bottom at a depth of 309 feet below the present surface. Minor extensions of the main buried valley continue up the Lackawanna Valley as far as Duryea, up Mill Creek to the region around Miners Mills, and up Newport Creek as far as Glen Lyon. (See Figures 42, 43, and 44.)

The erosional work of the ice as it moved across the region in all probability is responsible for the buried valley of the Susquehanna and its minor extensions. The main mass of ice must have moved diagonally southward across the valley while the ice in the lower portion was deflected along the axis of the valley. In the waning stages when the ice had melted from the mountain tops all the ice in the valley must have moved parallel to the valley axis. This movement must have resulted in a plucking and gouging action with development of troughs and holes in the soft materials of the valley bottom. During this movement, streams flowing beneath the ice may have helped to deepen these holes and basins. The old buried valley is thus believed to be the result of gouging and overdeepening on the part of the ice, possibly aided by powerful currents working underneath.

When the ice began to melt in the valley, the debris from the ice and that brought in by streams was deposited in the overdeepened channel, so that the filling of the valley represents accumulations of glacial till mixed with various stream deposits.

Scoured Mountain Surfaces

Wilkes-Barre Mountain makes up the inner rim surrounding the valley in the southwestern part of the area. (See Figure 23.) Its northern flank reveals numerous areas of considerable magnitude that are quite barren of vegetation. Seen from the center of the valley these barren patches appear like great white blotches arranged in an irregular pattern in the otherwise green-covered mountain side. These barren patches are surface exposures of the Pottsville conglomerate. Seen close at hand they are found to have been scoured and polished. This must have been done by sand and hard rock fragments embedded in the glacial ice. As the ice sheet crossed the valley almost transversely it must have exerted a tremendous scouring action on the northern slope of Wilkes-Barre Mountain. Some of the areas show surfaces as smooth and highly polished as ornamental granite polished artificially. The fresh appearance of the rock, its absolute lack of weathering, gives one the impression that the planing and scouring could have been done but a few years ago at the most. Yet we know that this scouring could only have been accomplished by the ice sheet some thousands of years ago.

Either the rocks which have preserved this ancient polish so remarkably have been covered up with glacial deposits until recently, and so have had their surface preserved from weathering, or the surface has been smoothed to such an extent that with an absence of any great number of joints, infiltration of moisture has been at a minimum. Many of the barren areas are near the top of the mountain and have a slope of 40-50 degrees, so that any accumulation of debris would be rather easily washed from the surface at an early date. It seems most probable that they represent those few remaining areas of the mountain side which, either through favorable position or freedom from flaws (such as soft material, poor or little cement, many joints, etc.), have not succumbed to disintegration and decomposition. Where the planed and scoured surface of the rock on the mountain side was inferior for any reason, extensive weathering destroyed the polished surface and created a soil sufficient for abundant vegetation to take root.

MINOR DRAINAGE CHANGES RESULTING FROM GLACIATION

Changes in the Scranton Region

When the glacier dropped its accumulation of detritus at the end of the glacial period many former stream channels were blocked wholly or in part. As a result the streams found new outlets which most of them occupy at the present time. While the resulting topographic changes have been minor, several of them are of sufficient importance to need explanation.

Leggetts Creek, which flows southeastward through Clarks Gap, makes a sharp bend to the east in Providence (A, Figure 18). The stream from the bend to its junction with the Lackawanna River flows through a rocky channel whose upper walls are flanked by a thick till cover. The stream prior to the glacial period evidently flowed directly southeast through Providence, entering the Lackawanna about 1½ miles below its present junction. The old course, although built over, is known from the old stream channel deposits crossed during excavations for sewage disposal and water supply systems. (See Figure 19.)

Keyser Creek originally found its headwaters in the mountain side a mile or more west of Clarks Gap. (See B, Figure 18.) The whole lower area of the mountain side is covered with an extensive till sheet which grades into fan and kame deposits in the upper valley. The only barrier today between Keyser Creek and the stream draining into Leggetts Creek is the deposit of till and semi-stratified material 8 or 9 feet thick (B, Figure 18). A tributary of Leggetts Creek at the bend captured the headwaters of Keyser Creek.

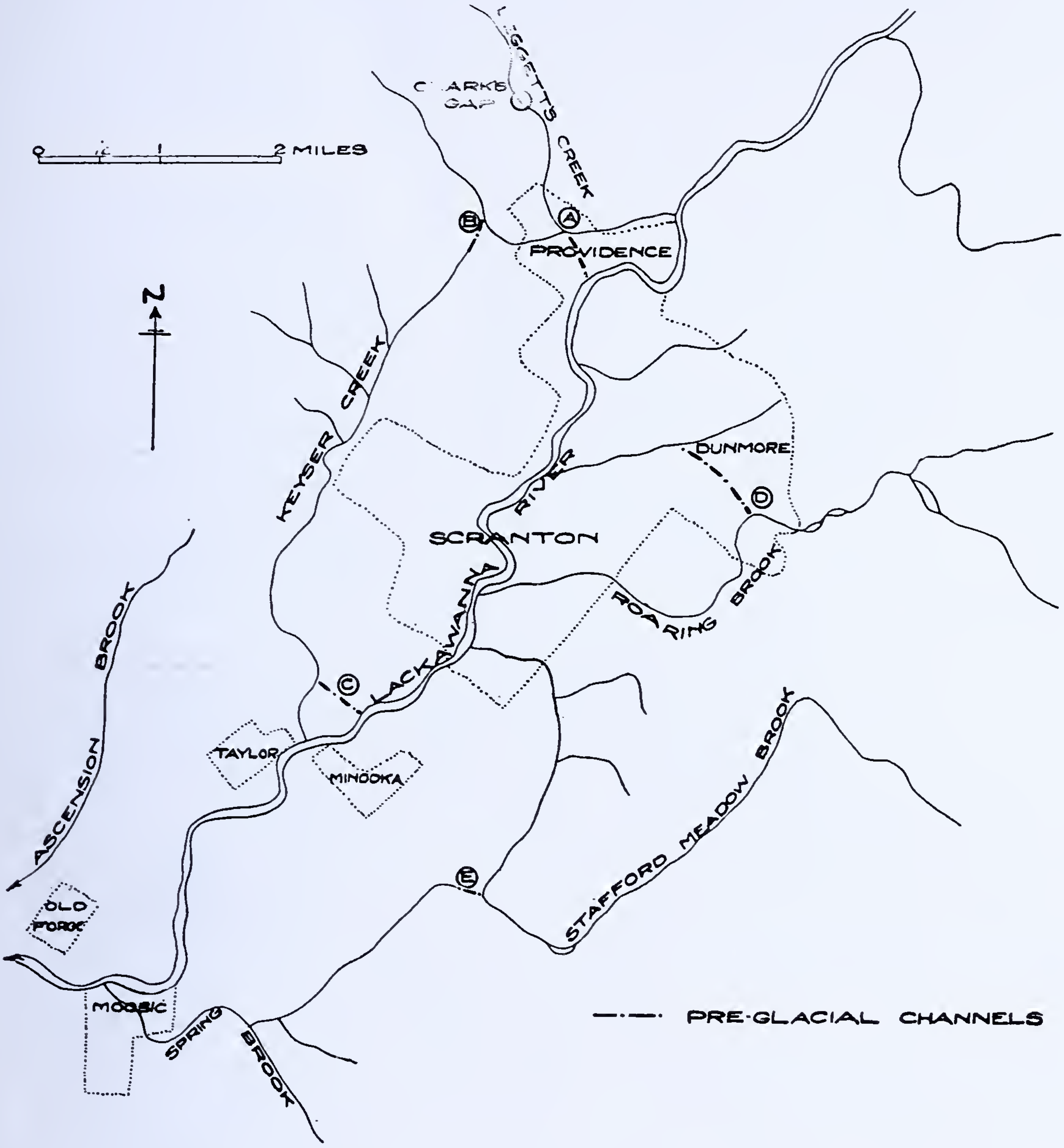


Figure 18. Present drainage in the Scranton region.

Keyser Creek today enters the Lackawanna River at the northeast end of Taylor. A little less than ½ mile northeast of the present stream junction the old channel of Keyser Creek is filled with extensive gravel deposits. (See C, Figure 18.) These must have been of sufficient thickness to force Keyser Creek to turn southwest and develop the channel which it has cut through the rock.

Two extremely interesting changes of drainage have taken place on the southeast side of the Lackawanna as a result of glaciation. Roaring Brook at the present time enters the Lackawanna between central and south Scranton. Throughout much of its lower course in the hills east of Scranton, it flows through a narrow rocky gorge, its grade interrupted by several waterfalls. The stream has evidently adopted this course since the glacial period, for an older channel may be traced northwest from the first sharp bend of Roaring Brook above Nay Aug Park (D, Figure 18). Stream deposits in the vicinity of the Erie Railroad station and exposed in two excavations in Dunmore show the approximate route of the old channel. The course now followed east of Nay Aug Park, through the park, and through Scranton is a post-glacial course.

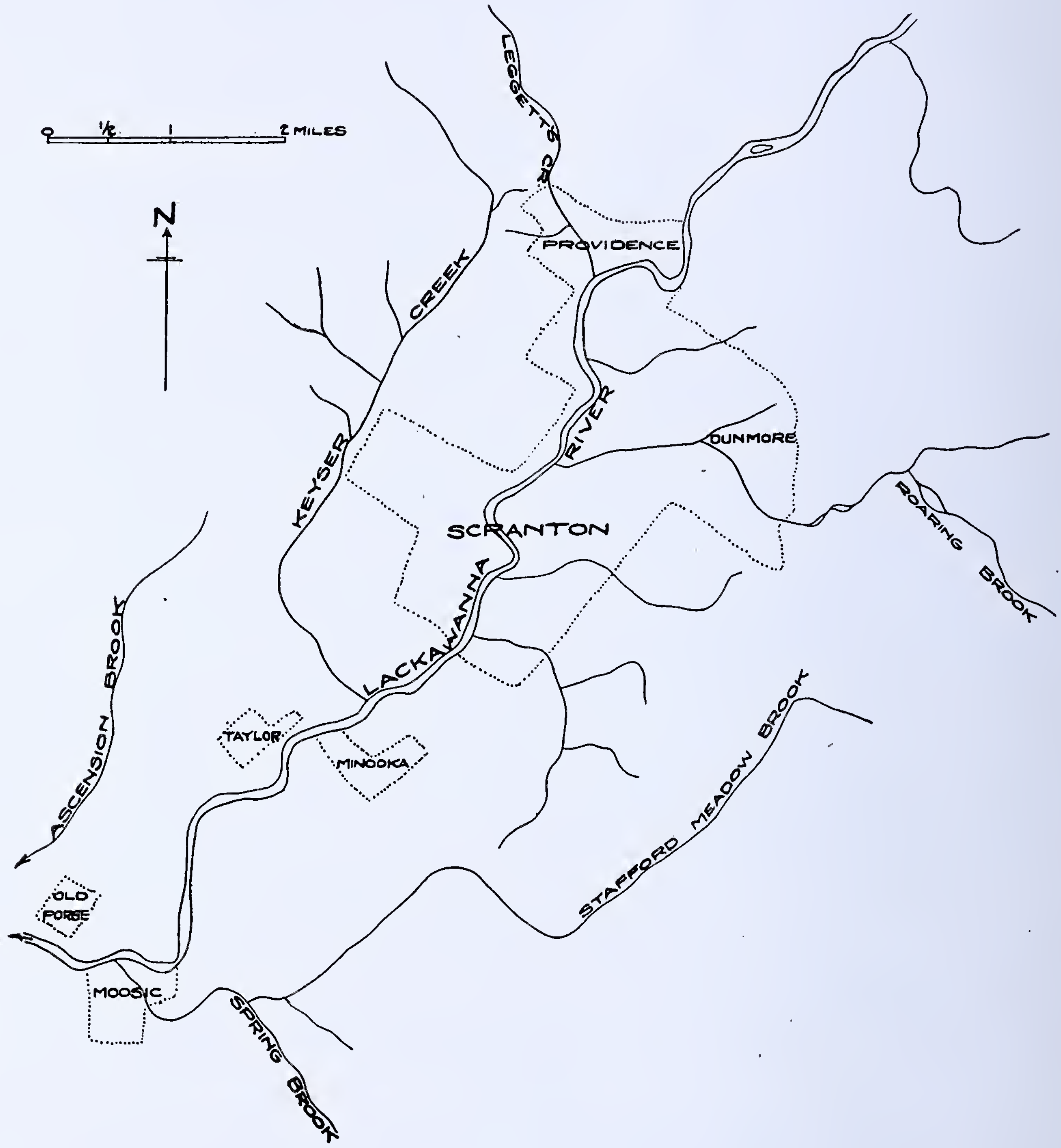


Figure 19. Probable preglacial drainage in the Scranton region.

Stafford Meadow Brook flows southwest for several miles, bends sharply to the northwest for a mile, and then north. A branch of Spring Brook heads at the second angle just mentioned (E, Figure

18), where there is thick till covered with stratified deposits. The old route of Stafford Meadow Brook must have been along the course now occupied by the branch of Spring Brook.

Changes in the Wyoming Valley

The probable preglacial course of Mill Creek is indicated on the accompanying sketch (Figure 20). The reasons for the abandonment of this course will be considered in the section dealing with geomorphic problems.

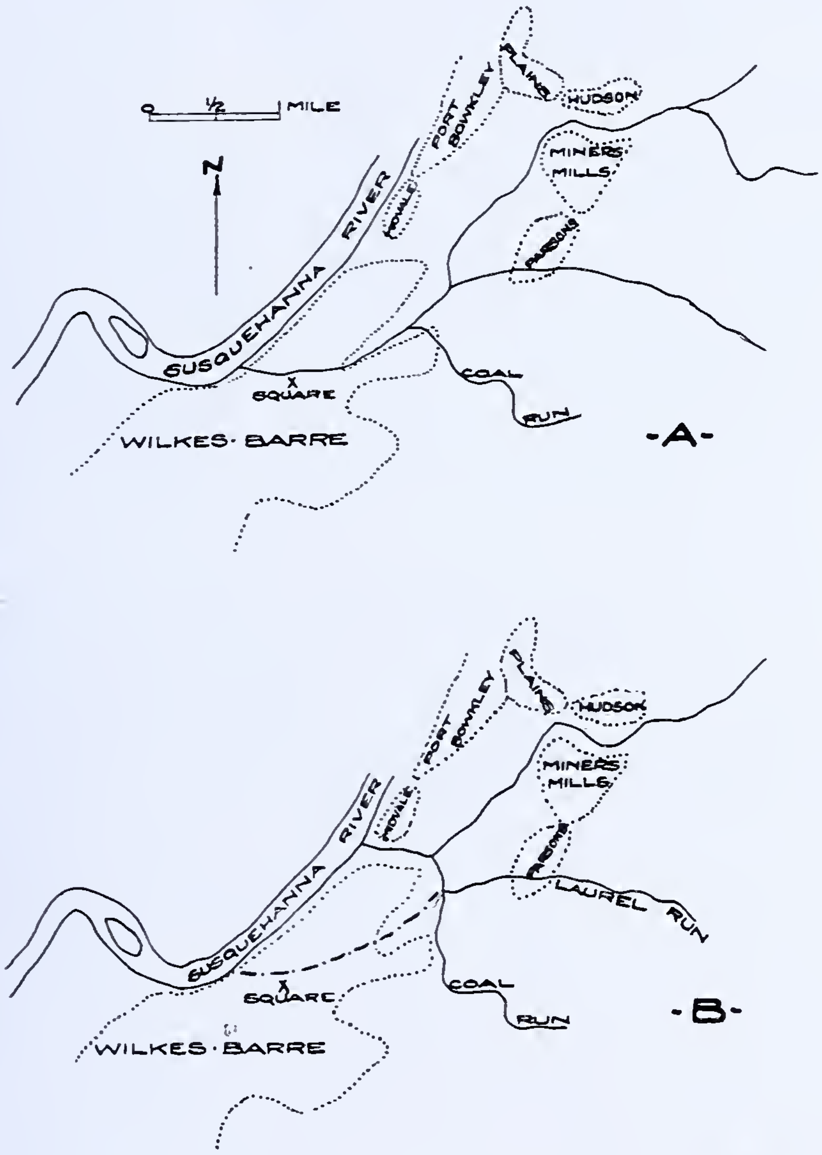


Figure 20. A. Probable preglacial course of Mill Creek.
B. Present course of Mill Creek.

Toby Creek had a different course during the latter part of the glacial period from that followed at the present time from Luzerne to Kingston. The course through Larksville, shown on Figure 21 (A), may well have been the preglacial channel occupied by the stream, for it follows the strike of the soft coal measure formations southwestward; or it may merely have been the course followed by Toby Creek during the waning stages of the Ice age. Apparently a barrier of ice lay near the point where the stream entered the valley. Toby Creek built a high delta fan and a considerable portion of the stream flowed southwest through upper Pringle and Larksville, depositing a delta in the area west of Edwardsville. The old course, marked by flood plain deposits, is seen in the cuts exposed in the upper part of Pringle.

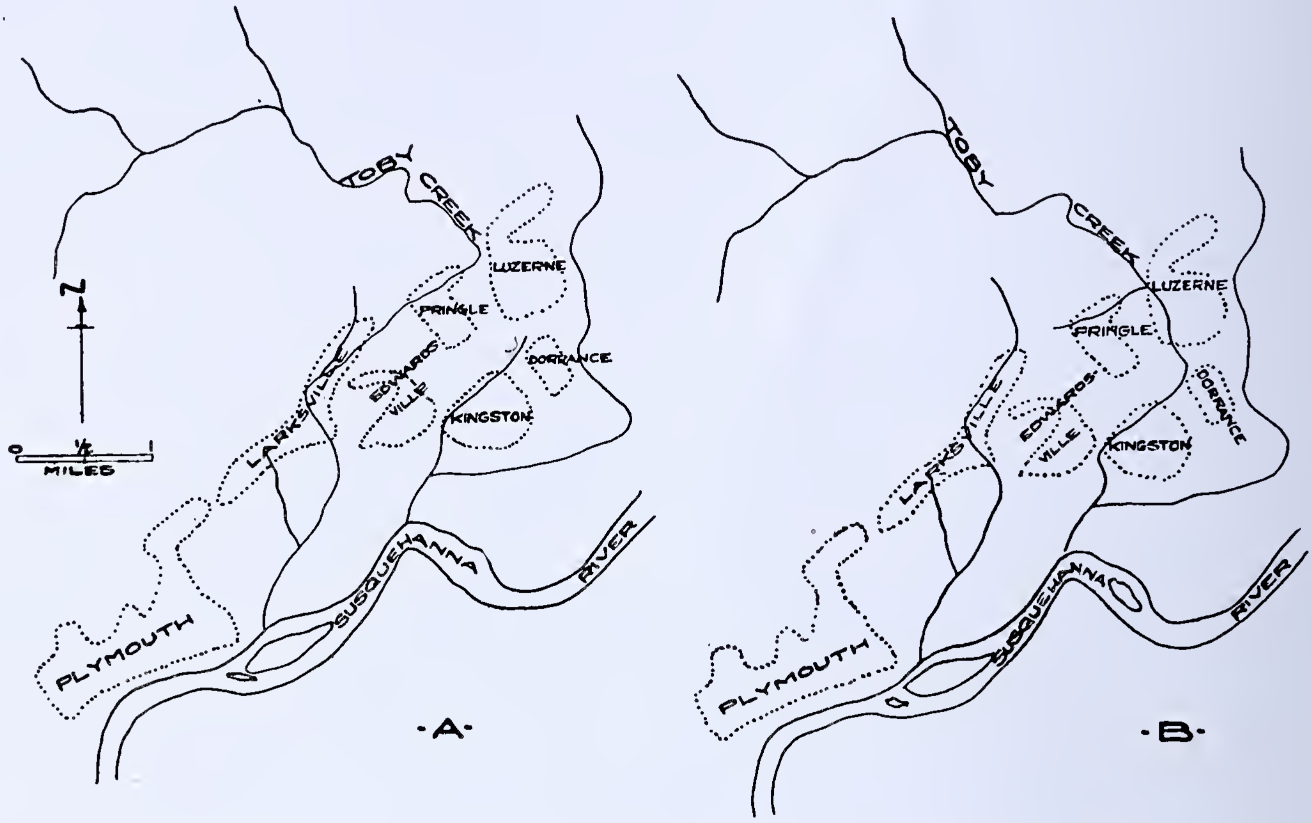


Figure 21. A. Probable preglacial course of Toby Creek.
B. Present course of Toby Creek.

THE PRESENT LANDSCAPE

EROSION SINCE THE PLEISTOCENE

The period since the ice of the Glacial epoch withdrew from continental North America is known as the Recent or Post-Pleistocene. The time in years has been estimated in a number of ways, the general conclusions being that 10,000 to 20,000 years have passed since the ice retreated. In this interval we might expect important changes in the landscape of the region, yet the work done constitutes a very minor addition to forms previously developed.

It does not appear that the general levels of the mountains and the main valley can have been materially lowered in this period. The mountain sides and crests still show smooth, polished, sometimes striated surfaces, virtually as fresh as when they were made by the glacier some thousands of years ago. Locally, streams coming down the mountain sides have undoubtedly deepened their old valleys and many of them have cut new channels in hard rock. Thus Roaring Brook in the Scranton area has cut a channel since the glacial period, as mentioned previously. Most of the erosional work in the area since the ice left is confined to the deepening of rocky gorges.

Other evidence which tends to show that the amount of erosion in this period has been comparatively slight is the fact that the depositional features originating near the close of the Pleistocene have been little altered. The marginal terraces appear to be very largely in their original form, with only minor stream erosion of the terrace fronts.

COURSES OF STREAMS ON THE SUSQUEHANNA FLOOD PLAIN

In the lower Mississippi flood plain the Yazoo River flows parallel to the Mississippi for about 100 miles before it enters the main stream. During times of flood the Mississippi drops much of its burden of sediment at the place where the swift water of the channel comes into contact with the more sluggish backwater, that is, along the edges of its channel, thus building natural levees. This process, combined with silting of the river bed, may raise the surface of the stream considerably above the level of the flood plain margin. Streams entering the flood plain may therefore be forced to parallel the main stream for many miles as is the case of the Yazoo. Such deflected tributaries are said to be of the Yazoo type.

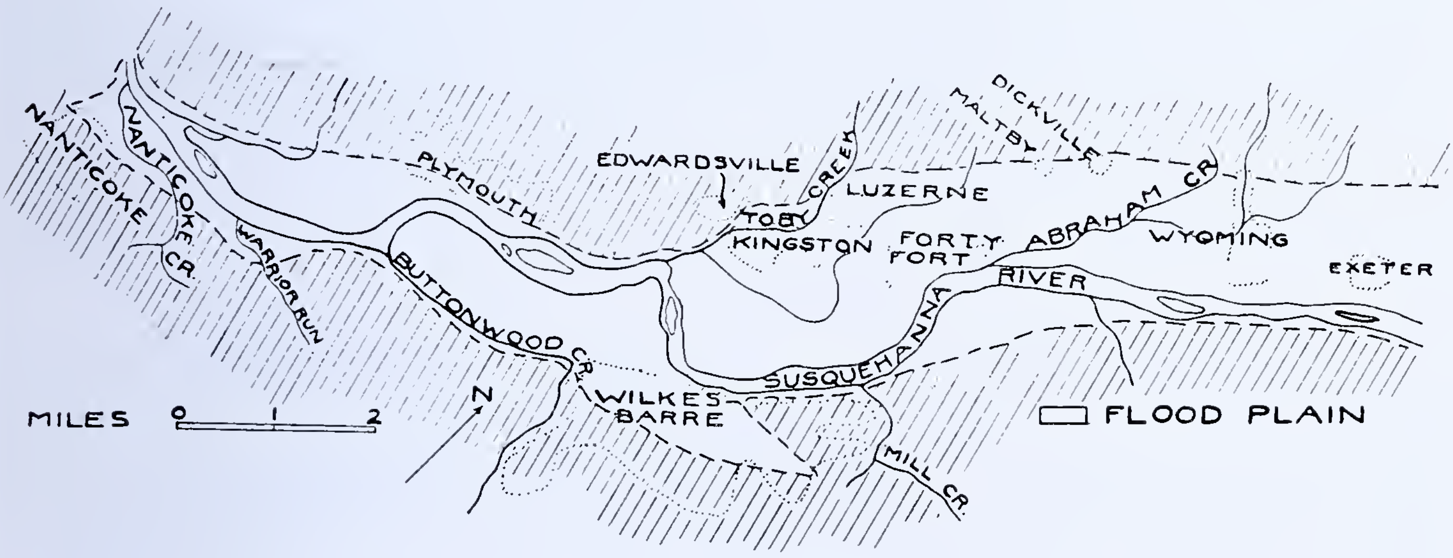


Figure 22. Yazoo type streams on the Susquehanna flood plain.

Since the withdrawal of the great ice sheet the Susquehanna River has filled in the depression gouged by the ice of the Glacial epoch. It now flows over a wide alluvial flat, much of which it may flood during periods of high water. As small streams come down from the mountains they follow fairly straight courses transverse to the main valley. When once they leave the hard rock area and emerge upon the flood plain of the Susquehanna, they tend to assume courses parallel to the main stream and are usually situated close to the rocky bluffs bordering the alluvial flats.

Probably the best example of the Yazoo type in the valley is Buttonwood Creek which enters the flood plain at the western edge of

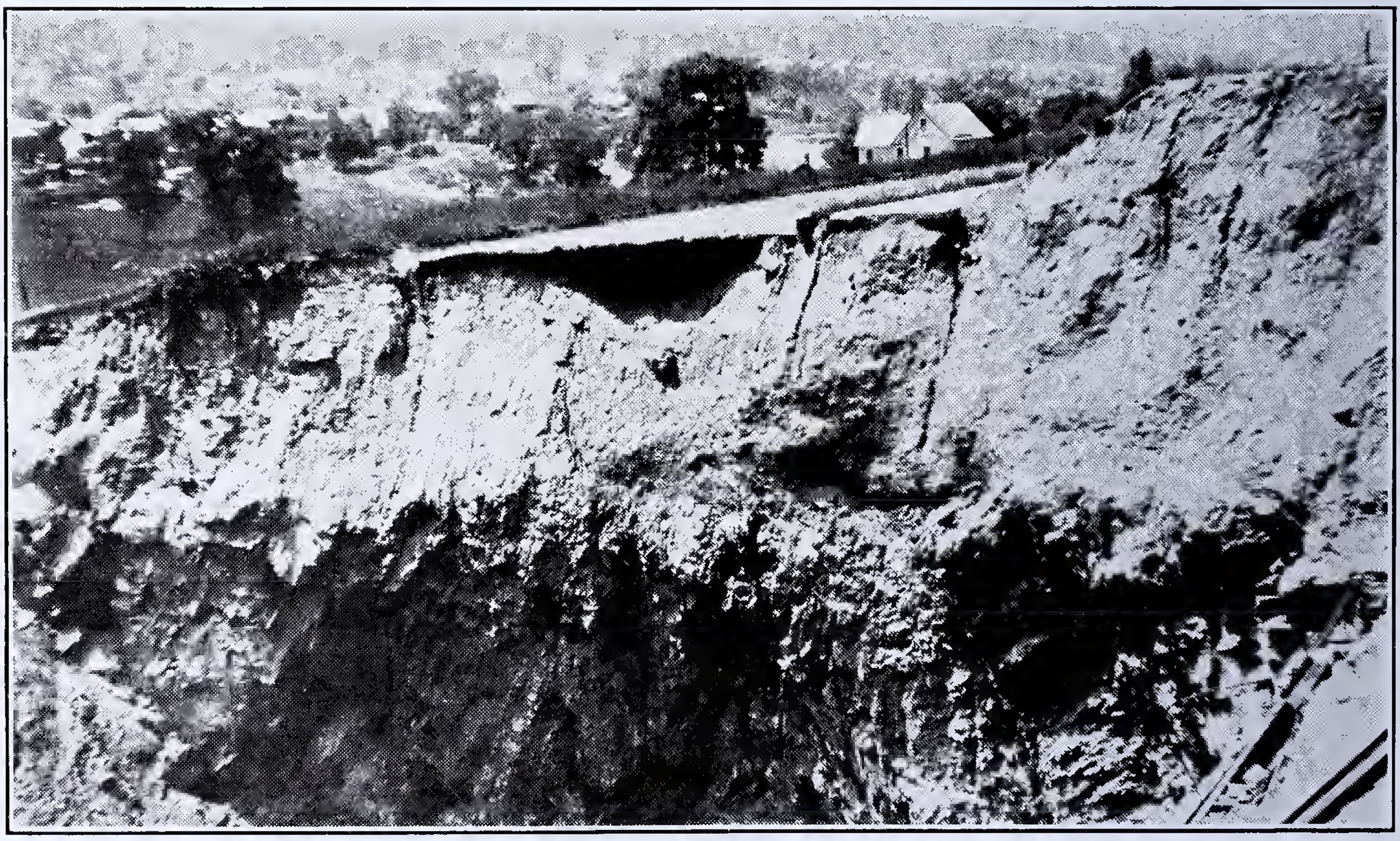
Wilkes-Barre and then turns westward paralleling the course of the Susquehanna for two miles. Other examples of the Yazoo type are Abraham Creek, Toby Creek and several minor streams northeast of Wilkes-Barre, and Warrior Creek, Nanticoke Creek, and other small streams in the western part of the valley. The relations of these streams are shown in Figure 22.

MAN AS A GEOMORPHOLOGIC AGENT

While this region remained the abode of the Indian very little change in the landscape resulted. After white men came to the valley,

PLATE 3

A. Burning culm banks at Nanticoke, Pa. The Susquehanna River is in the foreground, Penobscot Mountain forms the skyline. The upper portion of Nanticoke is built on a terrace the same height as Tilbury terrace from which this picture was taken.



B. Effects of caving. Site of schoolhouse which caved in on May 30, 1928. Alden, Pa.

about 200 years ago, many of the smaller forms now seen in the region came into being. Certainly the past 100 years, since the white man found that the hard black stones of the valley would burn, have seen a tremendous number of changes. It is unfortunate but apparently inevitable that where mining is conducted on an extensive scale ugly scars will be left to mar the natural beauty of the landscape. Almost 180 square miles of this valley are underlain with hard coal. There are approximately 5½ billion tons of anthracite still in the ground, which would give an average thickness of about 27 feet of coal underlying the field. Locally areas are underlain by 70 feet or more of coal, distributed, of course, in a number of beds.

Man has been engaged in removing this coal for at least 100 years and will undoubtedly continue for several centuries. In the process of mining he has done three things which mar the scenic beauty of the region. A great deal of waste rock is brought to the surface with the coal. The rocky waste is dumped on any unoccupied ground. These waste heaps or culm banks may be 100 feet high and present a huge mass of broken rock and coal on which little or no vegetation takes root. With approximately 150 collieries in the valley and with most of them having an independent waste heap, the result is a series of disfiguring hills of rock debris (Plate 3, A).

In those areas, usually well up on the lower mountain slopes, where the coal beds come to the surface, "stripping" of the coal has resulted in a series of deep ugly gashes. Frequently overlying debris will first be heaped to one side, forming a pile or groups of piles similar to the culm or refuse banks.

The third way in which mining affects the topography is by causing caving or subsidence. Where little effort was made to support the overlying formations mine subsidence has occurred in many places. In densely populated areas the coal operators today take steps to support the roof of the mines. Aside from general subsidence, which may result in a topography somewhat suggestive of a morainic deposit, deep "cave-ins" may occur. These "cave-ins" frequently occur suddenly with little or no warning. The accompanying photograph (Plate 3, B) shows the result of a cave-in at Alden, south of Nanticoke.

Certain minor topographic features develop as a result of processes used in preparing anthracite for market. A great quantity of water is used in cleaning and sizing the coal, and in the process large amounts of fine dirt and silt are derived which must either be dropped in desilting basins or permitted to enter the streams. Formerly most coal operators dumped much of this refuse directly into the streams. The additional sediment thus contributed to the normal stream load proved too great for the streams to carry, so that considerable sedimentation took place in the valley bottoms. Where a channel is thus filled the stream in it flows at a higher level than neighboring parts of its valley bottom. The stream then overflows at some point, scours out a passage through its low land and either takes an entirely new course over the valley bottom or divides into two distributaries, to unite again farther down the valley. The streams may repeatedly divide and subdivide in this manner, flowing in "braided" channels. Most of the smaller streams in their flatter courses exhibit this "braiding," especially in periods of low water.

At the present time most collieries have desilting basins, each of which may cover several acres. Where properly designed and constructed the basins catch much of the refuse but during periods of heavy rainfall nearly all of them permit great quantities of sediment to be washed into the streams.

The topography has been changed to a minor extent by man in his search for sand and gravel, in his cuts and fills for highways and railroads, in his leveling of areas for building sites, and in his creation of artificial lakes or reservoirs for water supply. These changes for the most part are minor and expectable in any fairly densely populated area. The major changes in the topography due to man are those associated with his mining activities.

SUMMARY

The present landscape in the Wyoming-Lackawanna region dates back only to Tertiary time. It is true that the region had been folded, and great mountains formed. The roots of these ancient mountains are preserved in the ridges that rim the valley. The present drainage lines were initiated on a coastal plain covering the old eroded surface. With uplift and erosion the area was reduced in Tertiary time to the Schooley surface. This Schooley surface is represented in the area only by the highest ridge crests. The Schooley surface was uplifted and a lower erosional level developed, known as the Harrisburg. During the time the Schooley and Harrisburg levels were developed the drainage lines as we see them today were established. The area was uplifted again and a new erosional surface developed very locally known as the Somerville. A final uplift in late Tertiary or more recent time interrupted the development of the Somerville surface and brought about the deepening of the stream valleys as generally observed today.

The normal cycle of erosional development was considerably changed in Pleistocene time by the repeated incursion of a great ice sheet which further modified the preglacial landscape. Since the last withdrawal of the ice normal erosional processes, together with the mining activities of man, have added numerous but minor changes to the pre-existing land forms.

BIBLIOGRAPHY

General References

College Geology: Chamberlin and Salisbury. Part I, Processes; Part II, Historical; Revised 1927 by Chamberlin and MacClintock; Henry Holt and Company, New York.

Textbook of Geology: Pirsson and Schuchert. Part I, Physical; Part II, Historical; John Wiley and Sons, New York.

The Earth and Its Rhythms: Schuchert and Le Vene; Appleton.

An Introduction to Earth History: H. W. Shimer; Ginn and Co., 1925.

The Quaternary Ice Age: W. B. Wright; MacMillan and Co.

Theories of Appalachian Evolution

The Rivers and Valleys of Pennsylvania: William Morris Davis; Nat. Geog. Mag., vol. I, 183-253, 1889.

Stream Sculpture on the Atlantic Slope: Douglas Johnson; Columbia University Press, New York, 1931.

References on Local Features

The Terminal Moraine: H. C. Lewis; Report Z, Second Penna. Geol. Survey, 1897.

Description of the Archbald Pot-Holes; also of the Buried Valley of Newport Creek Near Nanticoke with Special Reference to the Nanticoke Mine Disaster of December, 1885: Charles A. Ashburner; Annual Report, Second Penna. Geol. Survey, pp. 615-636, 1885.

Description of the Wyoming Buried Valley Between Pittston and Kingston: Frank A. Hill; Annual Report, Second Penna. Geol. Survey, pp. 637-647, 1885.

Some Features of the Quaternary Deposits in the Wyoming Valley Region: N. H. Darton; Proc. Wyoming Historical and Geological Society; Vol. XIII, pp. 41-64, 1914.

PART II

FEATURES OF THE MAJOR DRAINAGE

THEORIES OF APPALACHIAN DRAINAGE

The particular feature of Appalachian drainage most difficult adequately to explain is the remarkably direct parallel southeast courses of parts of the master streams and some of the lesser drainage. The Davisian hypothesis[1] attempts to account for present drainage in part as ancient consequent northwest drainage initially established on the primary Appalachian folds. The northwestward-flowing streams were reversed to the southeast by faulting and depression in the southeastern portion of Pennsylvania and in New Jersey in Newark (Triassic) time. Davis also suggested that the reversal might have been accomplished by small Atlantic coastal streams which worked headward and captured the headwaters of the mighty northwestward-flowing streams, thus ultimately reversing them. The drainage was further modified by subsequent development along weak rock formations. As of considerable interest Davis suggested that the major northwestward-flowing stream, the "Anthracite," found its headwaters in lakes which occupied the synclinal basins of the Anthracite Fields.

The writer does not propose entering into any extended discussion of the Davisian hypothesis. The chief objections to it are fully set forth by Johnson in the work cited below.

Certain students of Appalachian geomorphology have offered simple reversal due to the tilting of the Schooley surface as an explanation of the southeast courses of the present streams. This view is expressed by Miller[2] who states:

> "The south and southeasterly drainage lines were established as a result of the uplift of the peneplain . . . It is very reasonable, if not highly probable, that this very warping or slow arching up of the peneplain surface inaugurated the present drainage toward the Atlantic because the streams, no matter what their previous courses, then naturally must have flowed down that initial slope toward the Atlantic.

This explanation must be regarded as highly improbable, since the angle of tilt and the rate of warping would have to be abnormally high in order to reverse the flow of a master stream, even though that stream have a wide shallow valley on a peneplane. The observed angle of tilting on the Schooley peneplane is very low and hardly sufficient to initiate any drastic reversal of direction.

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[1] William Morris Davis: Rivers and Valleys of Pennsylvania, National Geographic Magazine, vol. I, pp. 183-253, 1889.

[2] William J. Miller: The Geological History of New York State, New York State Museum Bulletin 168, p. 84, 1914.

The reader will bear in mind that these efforts to explain the present trend of the drainage have met their greatest stumbling block in the attempt to reverse the direction of drainage of well-established master streams. The question may be asked as to the necessity of drainage reversal. Would the problem not be much simpler if some adequate explanation could be found which would not necessitate any perplexing reversal of drainage?

The only theory as yet brought forth which does away with the necessity of reversing the drainage is that of Johnson.[3] The gist of his theory of "Regional Superposition of Appalachian Drainage" is as follows:

> "Beginning in Cretaceous time . . . the sea is supposed to have spread far inland over the Fall Zone peneplane (Cretaceous peneplane) and to have buried that relatively even erosion surface and its continental deposits with a mantle of Cretaceous and possibly later sediments. Thus all the drainage adjustments of the early cycle were completely obliterated. Later a broad uparching of the Appalachian region initiated upon the exposed covering deposits a new consequent drainage system, traces of which may persist to the present day. Then during the Tertiary came the long Schooley cycle (or Kittatinny and Schooley cycles) of erosion, ending in production of the remarkably well-developed and widespread Schooley peneplane which beveled both the ancient crystallines and the coastal plain deposits. Many superposed southeast-flowing consequent streams held their courses across the Appalachian structures although during this long erosion period much adjustment of drainage to structure must have been accomplished.
>
> "Uparching of the Schooley peneplane permitted rejuvenation of the drainage and in due time development of the Harrisburg peneplane on weak rock areas. Further moderate uplift allowed incision of streams in the Harrisburg level and development of the Somerville peneplane on rocks of excessive weakness, such as limestones and certain shales. Finally, renewed uplift may account for the intrenchment of rejuvenated streams below the Somerville level. Thus the later stages of Appalachian history are believed to follow the sequence as set forth by Davis, Campbell, and other students of the region many years ago."

THE NORTH BRANCH OF THE SUSQUEHANNA ABOVE THE WYOMING VALLEY

The most important drainage problems in the region deal with the North Branch of the Susquehanna. This stream follows a nearly direct southeast course of almost 150 miles from New York State to the Wyoming Valley, where after breaking through the rimming mountains it bends sharply to the southwest. Above the valley the river flows transverse to the structure; in the valley it follows the strike (Figure 23).

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[3] Douglas Johnson: Stream Sculpture on the Atlantic Slope, Columbia University Press, 1931, New York. See p. 21.

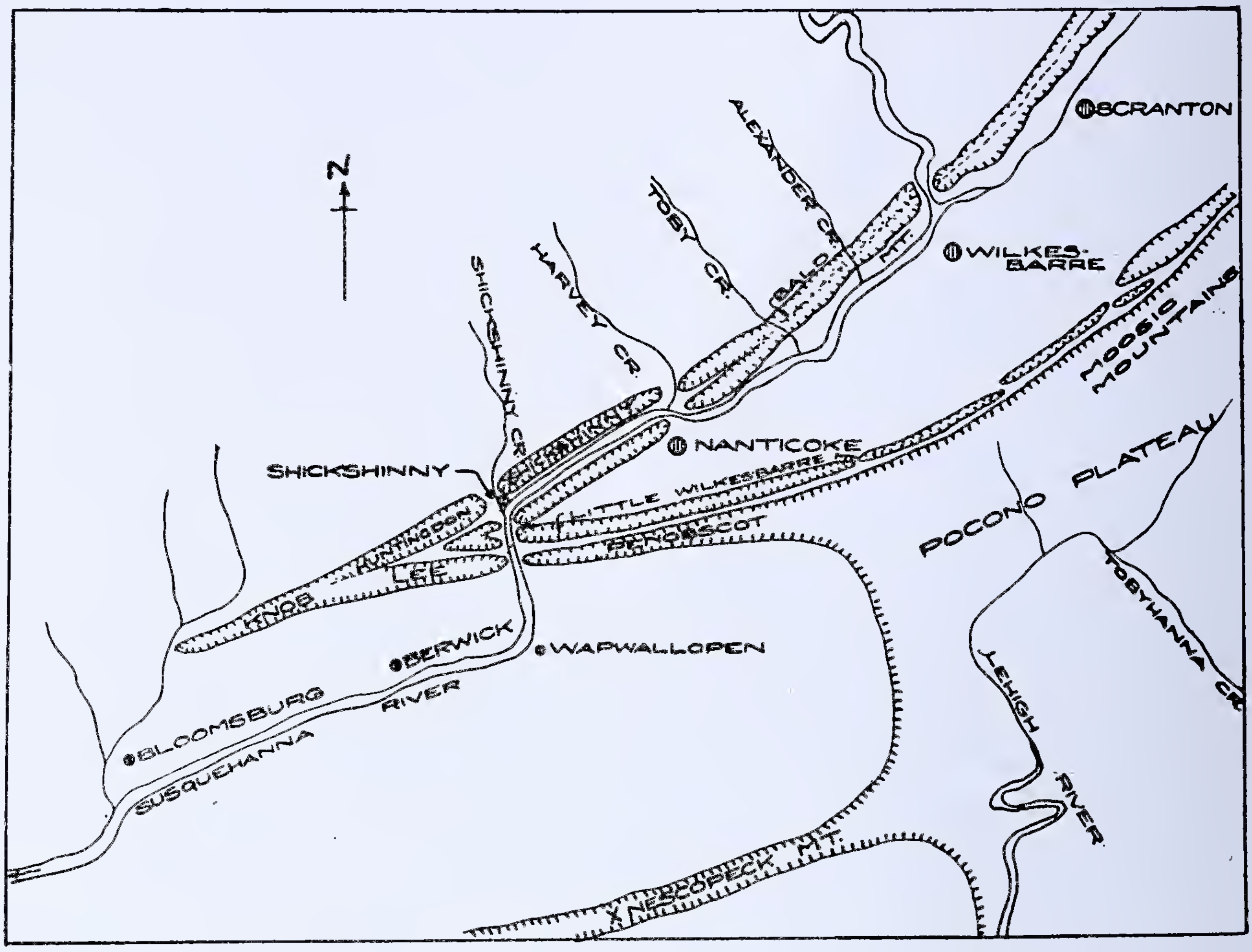

Figure 23. Susquehanna drainage in the Wyoming region.

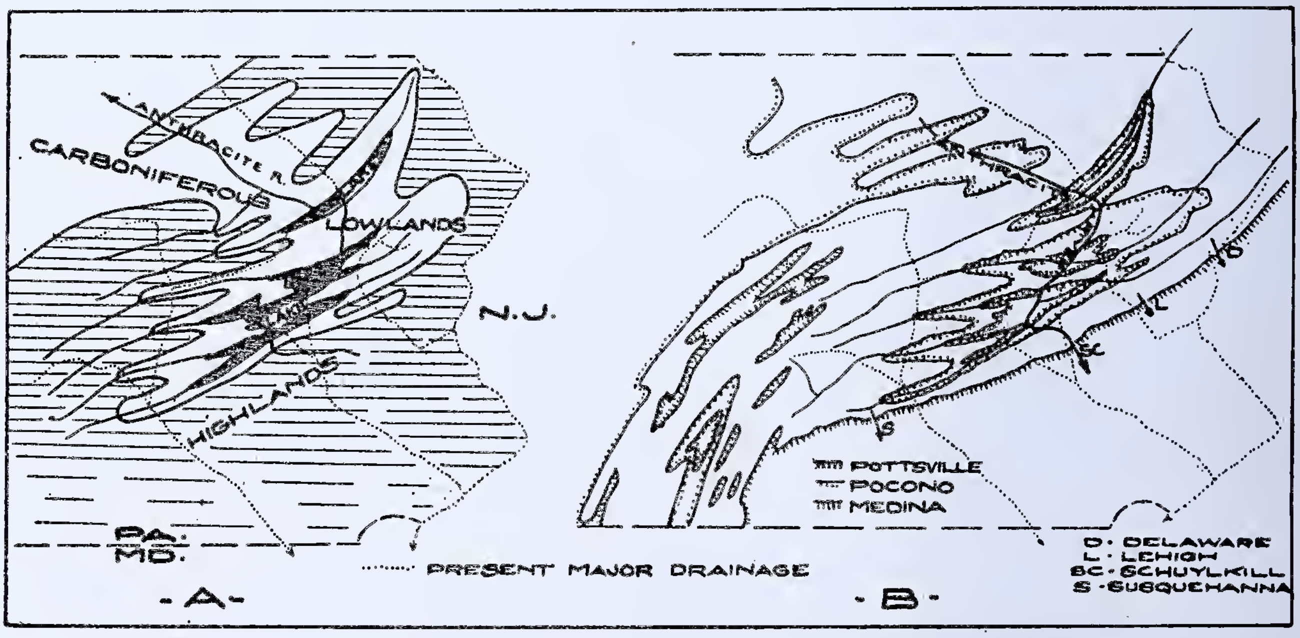

Figure 24. A. Original drainage of Pennsylvania based on Permian topography. (After Davis.)
B. Early Jurassic drainage in Pennsylvania as the result of reversal during Newark time. (After Davis.)

Figure 24 A illustrates the original drainage of eastern Pennsylvania based on the Davisian hypothesis. Figure 24 B shows the presumable drainage following the reversal of the master streams in Newark time. It will be noted that the original "Anthracite River"

must have followed a course considerably southwest of that now followed by the North Branch of the Susquehanna above the Wyoming Valley. The assumed location of this original major line of drainage is a necessity according to the tenets of the Davisian hypothesis. As the master stream carrying the overflow of the Anthracite lake off to the northwest, the stream must have followed synclinal axes and crossed anticlinal ridges only at the lowest points of their crest. Since the upper North Branch Susquehanna presumably represents the adjusted course of the Anthracite River the question

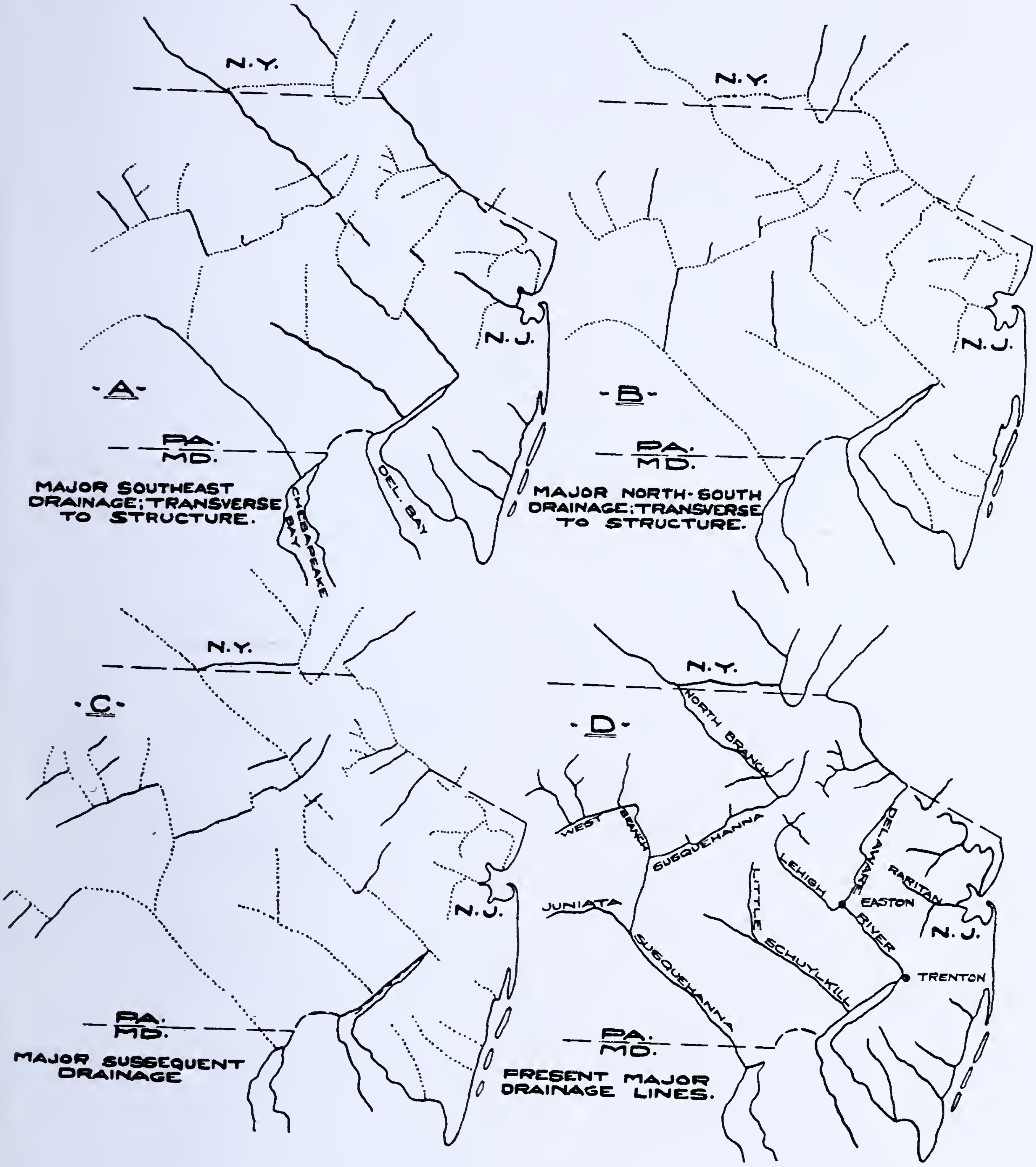

Figure 25. Major elements of the present drainage of eastern Pennsylvania and northern New Jersey.

arises as to the manner in which this drainage shift was accomplished. Davis very frankly states his inability to relate the location of the upper North Branch of the Susquehanna to processes of adjustment and considers it a doubtful case for which no satisfactory explanation has been found.

According to the Johnsonian theory the position of the upper North Branch of the Susquehanna and its remarkably long, relatively straight course presents no great problem. Both these features are expectable and necessary parts of the drainage history. The assumption is made that the river here owes its present location to inheritance of an original course consequent on a coastal plain. This theory thus does away with the necessity of finding some means whereby the Anthracite River, after its reversal, migrated bodily northeastwards.

In substantiation of this theory it may be observed that:

A. The long, remarkably direct southeast course of the stream is similar to the consequent type normally developed on a coastal plain.

B. The limited adjustment to structure is an expectable result of the inheritance of the major course through superposition.

C. The upper North Branch of the Susquehanna if extended southeastward would pass approximately through the wind gap at Pen Argyl and follow the route of the lower Delaware from Easton to Trenton. The relationship exhibited between these two streams is not believed accidental, for the same relationship is seen between the other major streams of eastern Pennsylvania and northern New Jersey. (See Figure 25A and D.)

THE NORTH BRANCH OF THE SUSQUEHANNA AT NANTICOKE

At Nanticoke (see Figure 23) the Susquehanna is deflected northwest, and after cutting across the Pottsville ridge, the river follows a narrow shale valley southwest before turning south and leaving the basin. The Davisian hypothesis regards that portion of the river within the Wyoming basin as the only considerable remnant of the old Anthracite River that still retains a course along the axis of a synclinal trough. The reason for this as suggested by Davis[4] is found in the great depth of the Wyoming basin, whereby the axial portions of its hard sandstones are even now below base-level, and have therefore never served to throw the river from its axial course. During various erosional cycles the basin must have changed from a

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[4] William Morris Davis: idem, p. 237.

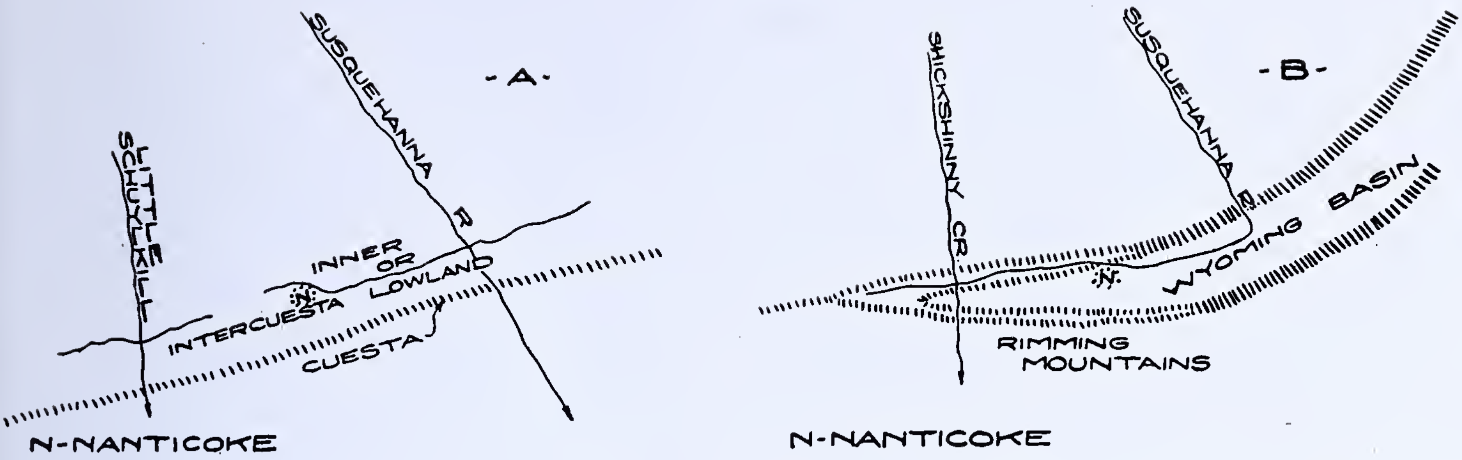

Figure 26. A. Development of a subsequent branch of the Susquehanna River in an inner or intercuesta lowland.
B. Superposition of the subsequent on the structure at Nanticoke.

deep lake to a lacustrine plain by the accumulation in it of waste from the surrounding highlands. For a time the streams that entered it may have flowed in meandering courses across the ancient alluvial surface. The present deflection at Nanticoke may possibly be regarded as an inheritance from a course thus locally superimposed.

While inheritance of a course due to superposition is here brought into play, it will be borne in mind that this is an application of a principle to meet the exigencies of an individual case. The same principle may be invoked under the Johnsonian hypothesis, where it is a normal consequence of the theory of regional superposition from a coastal plain. According to the latter hypothesis the present Susquehanna within the syncline might be considered as an ancient subsequent stream, probably a branch of the Ancient North Branch Susquehanna, developed either in an inner or possibly an intercuesta lowland as shown in Figure 26 A. With stripping of the coastal plain cover such a stream might reasonably be expected to suffer superposition on the structure. (Figure 26 B.)

Plate 4. The Susquehanna River leaving the syncline at Shickshinny. Water gaps cut through Pocono and Pottsville formations.

Susquehanna Water Gaps at Shickshinny.—Near the west end of the Wyoming basin the North Branch of the Susquehanna turns sharply southwards and cuts three gaps through the Pottsville and Pocono ridges as it leaves the valley. To the north of these three gaps Shickshinny Creek has cut a fourth through Shickshinny Mountain. The important feature associated with these gaps is their definite alignment in a direction slightly northwest-southeast. (Plate 4.)

The alignment of gaps was recognized by Davis as one of the stumbling blocks to an acceptance of his theory of drainage evolution. Under his list of doubtful cases Davis[5] says:

> "For example, the four gaps cut in the two pairs of Pocono and Pottsville outcrops at the west end of the Wyoming syncline, and the three gaps where the Little Schuylkill crosses the coal basin at Tamaqua . . . savors of an antecedent origin."

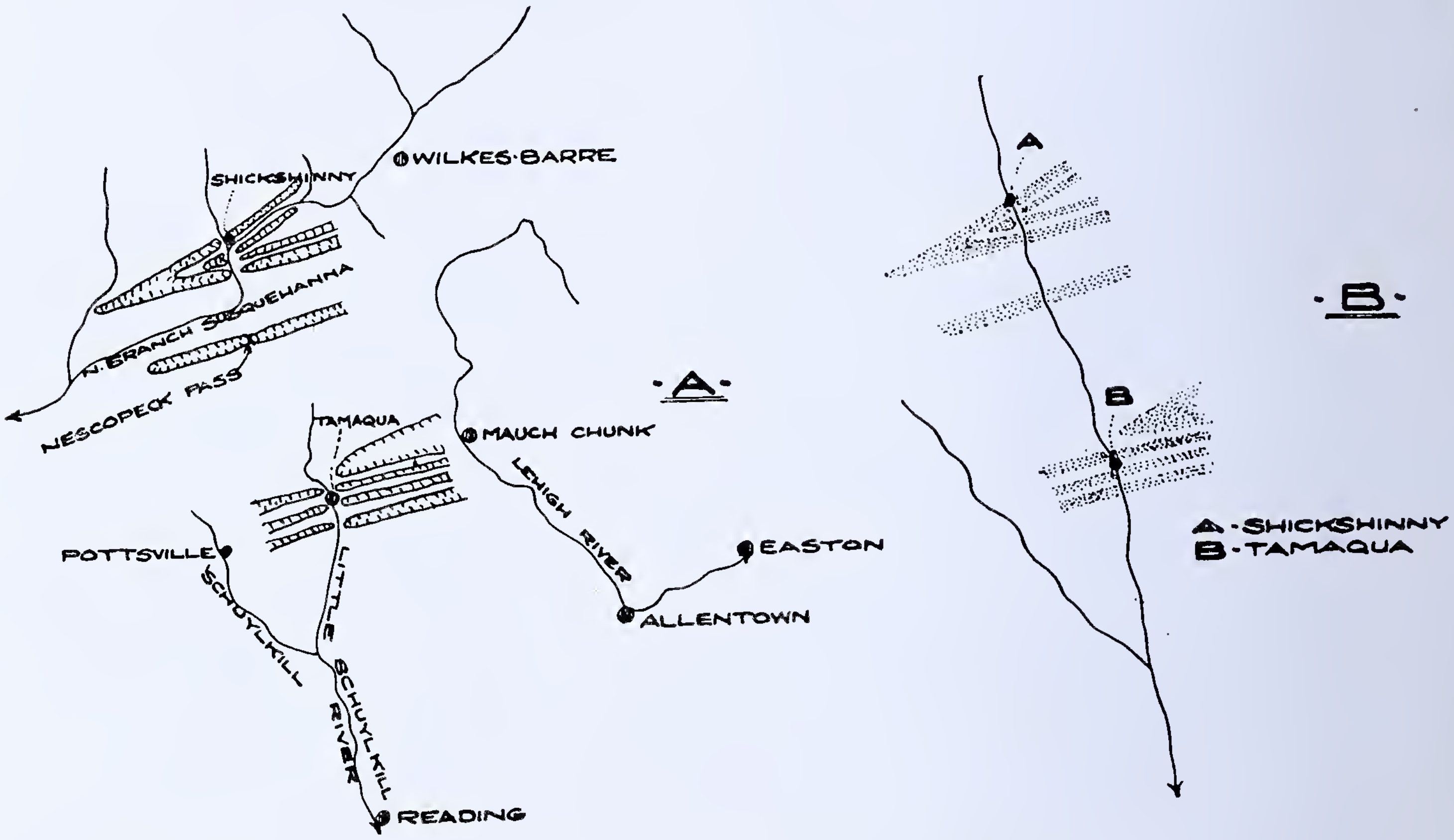

Figure 27. A. Water gaps at Shickshinny and Tamaqua.
B. Hypothetical course of the Little Schuylkill as developed on the coastal plain.

While Davis there recognized that the normal dissection of folded mountains and the modification of consequent drainage by subsequent development do not offer a reasonable explanation of gap alignment, he also pointed out difficulties preventing acceptance of the theory of antecedence.

The theory of regional superposition involves the alignment of water gaps and wind gaps as a normal necessary feature. As is pointed out by Johnson,[6]

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[5] William Morris Davis: idem, p. 251.

[6] Douglas Johnson: Stream Sculpture on the Atlantic Slope, Columbia University Press, 133 pp., 1931. See p. 37.

> "By providing for southeast-flowing streams on a coastal plain cover the theory requires that when such streams are superposed on underlying Appalachian structures the resulting hard rock ridges must be cut by a succession of gaps aligned as the streams flowed—from northwest to southeast."

On the basis of the latter hypothesis we might reasonably expect not only a series of closely aligned water gaps in one district, where the southeast drainage has been deflected in comparatively recent time we might also expect wind gaps aligned with the water gaps; and where portions of ancient drainage have been integrated into new systems we may find in the alignment of water gaps and wind gaps indication of their former continuity.

Figure 27 A shows the location of the four water gaps of Shickshinny Creek and North Branch of the Susquehanna through the Pocono and Pottsville ridges near the west end of the Wyoming basin and the three gaps of the Little Schuylkill through Nesquehoning, Pisgah, and Mauch Chunk Mountains. Whereas Davis considers these two series of aligned water gaps as militating against his theory, the fact that the two series align so beautifully must be regarded as strong evidence favoring the theory of regional superposition. In Figure 27 B the hypothetical course of the Little Schuylkill as developed on the coastal plain is shown. With any considerable deflection of drainage in the middle course of the stream the relations as shown in Figure 27 A might very reasonably be expected to occur. A further suggestion that the Little Schuylkill once held the course as shown on Figure 27 B is indicated in the pass over Nescopeck Mountain, now followed by the main highway be-

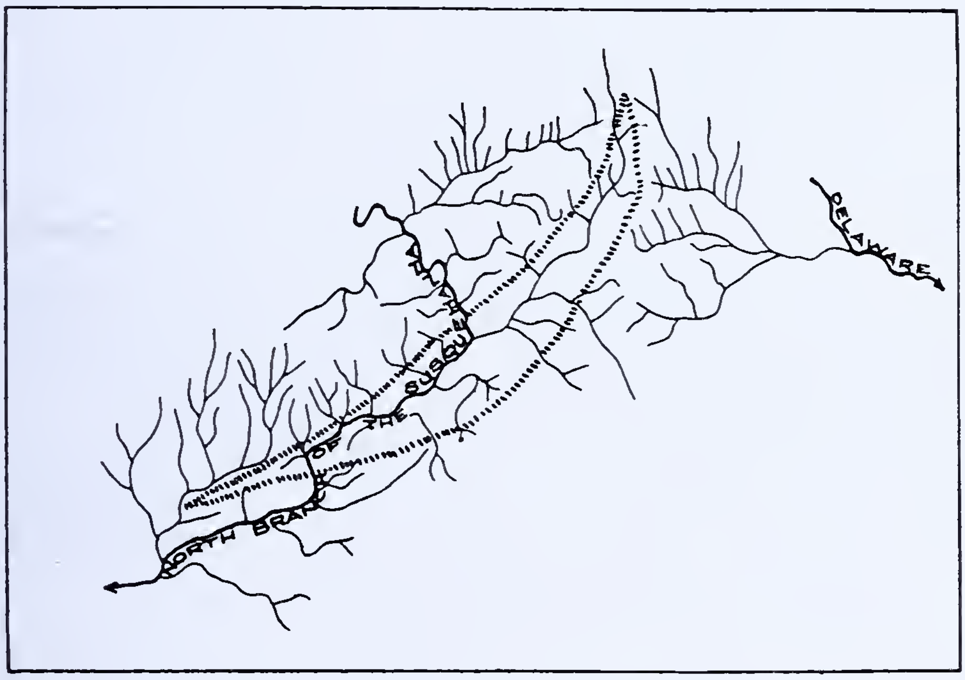

Figure 28. Centripetal drainage of the Wyoming-Lackawanna region. (After Davis.)

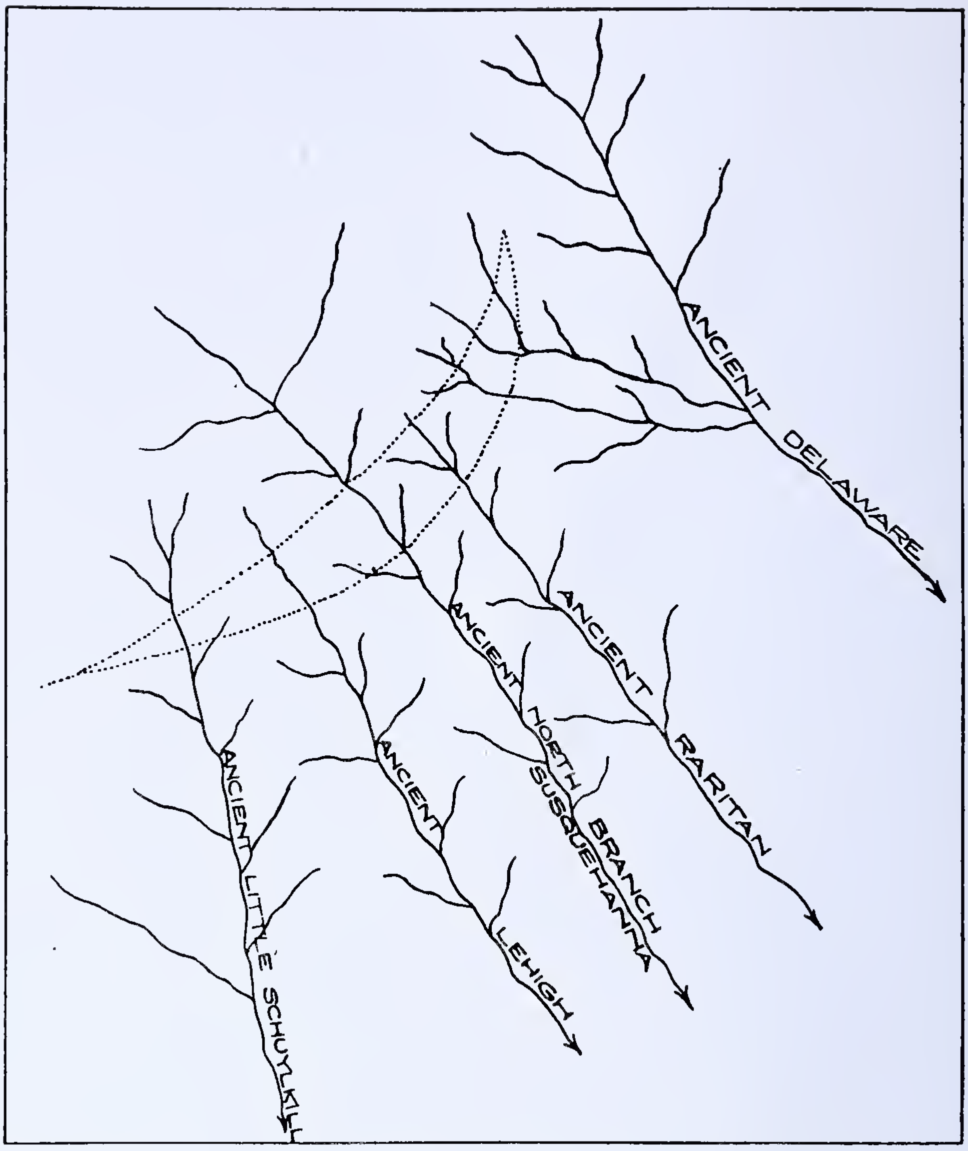

Figure 29. Type of original drainage on the coastal plain.

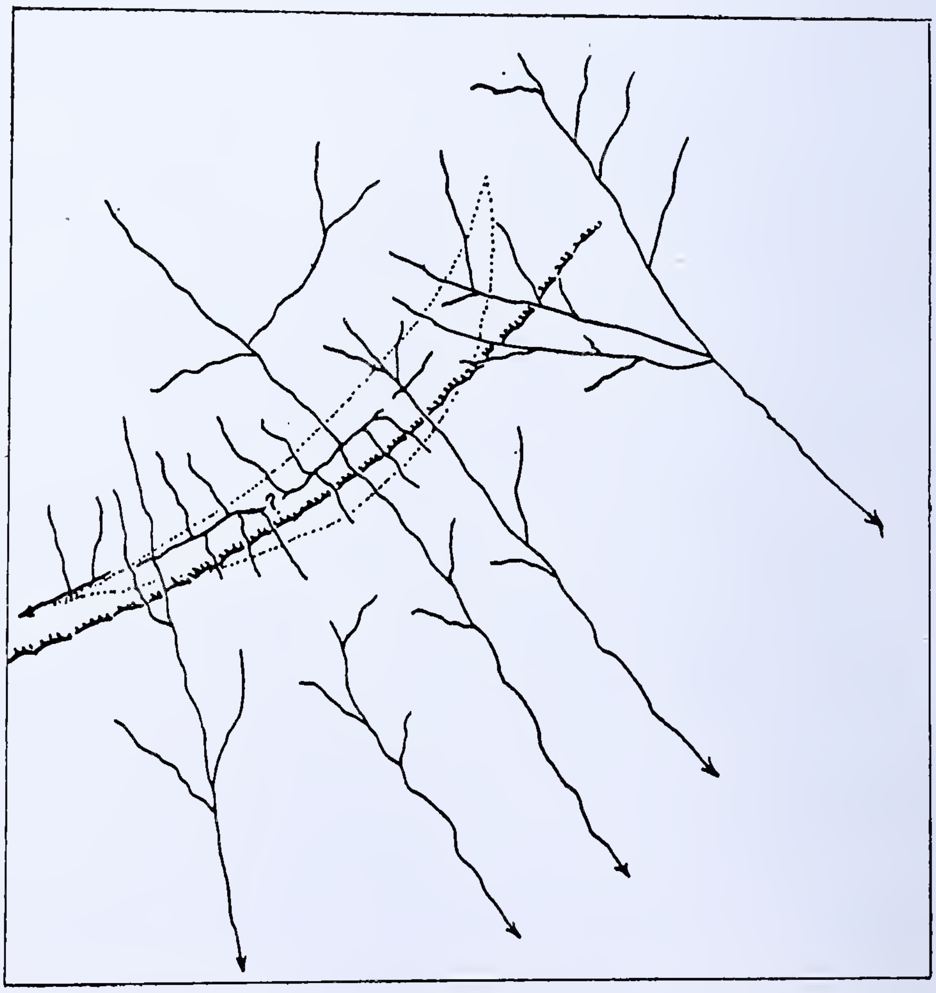

Figure 30. Development of cuesta and inner lowland in early stage of the Schooley cycle.

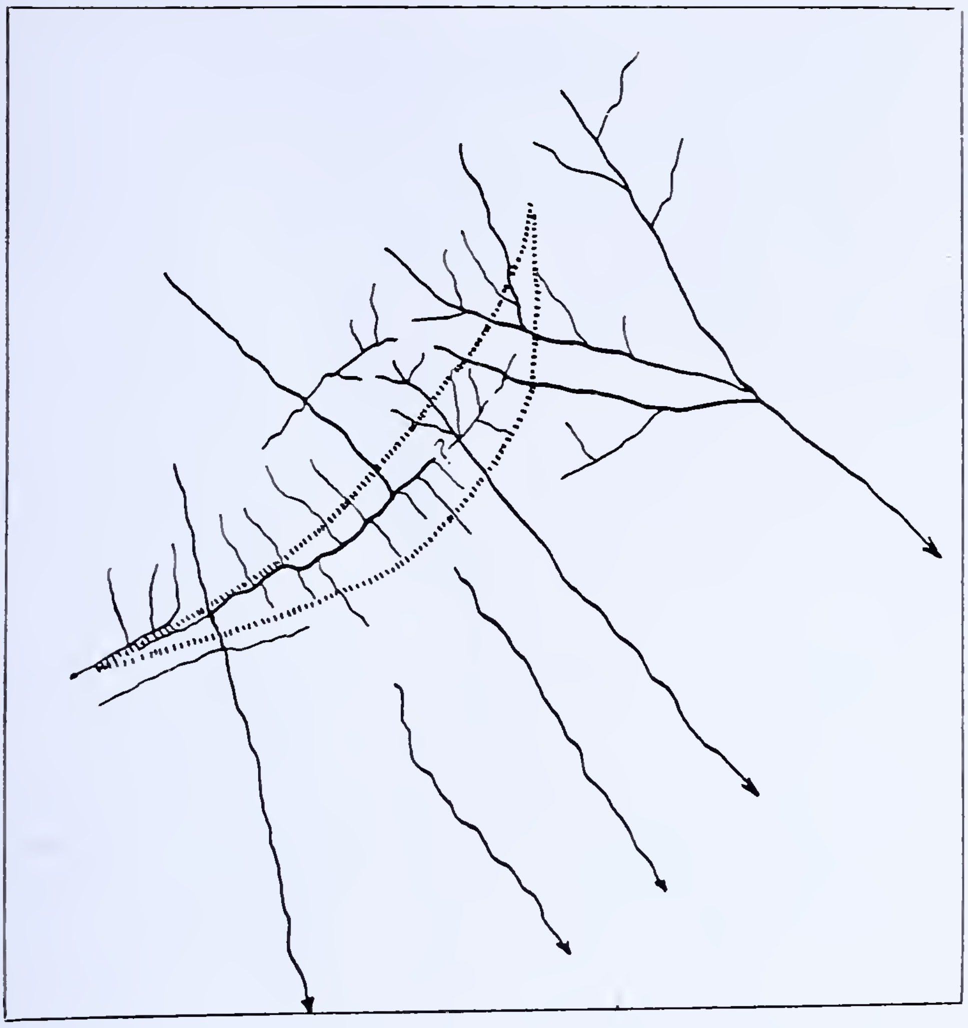

Figure 31. Development of drainage with removal of coastal plain and superposition on underlying structure.

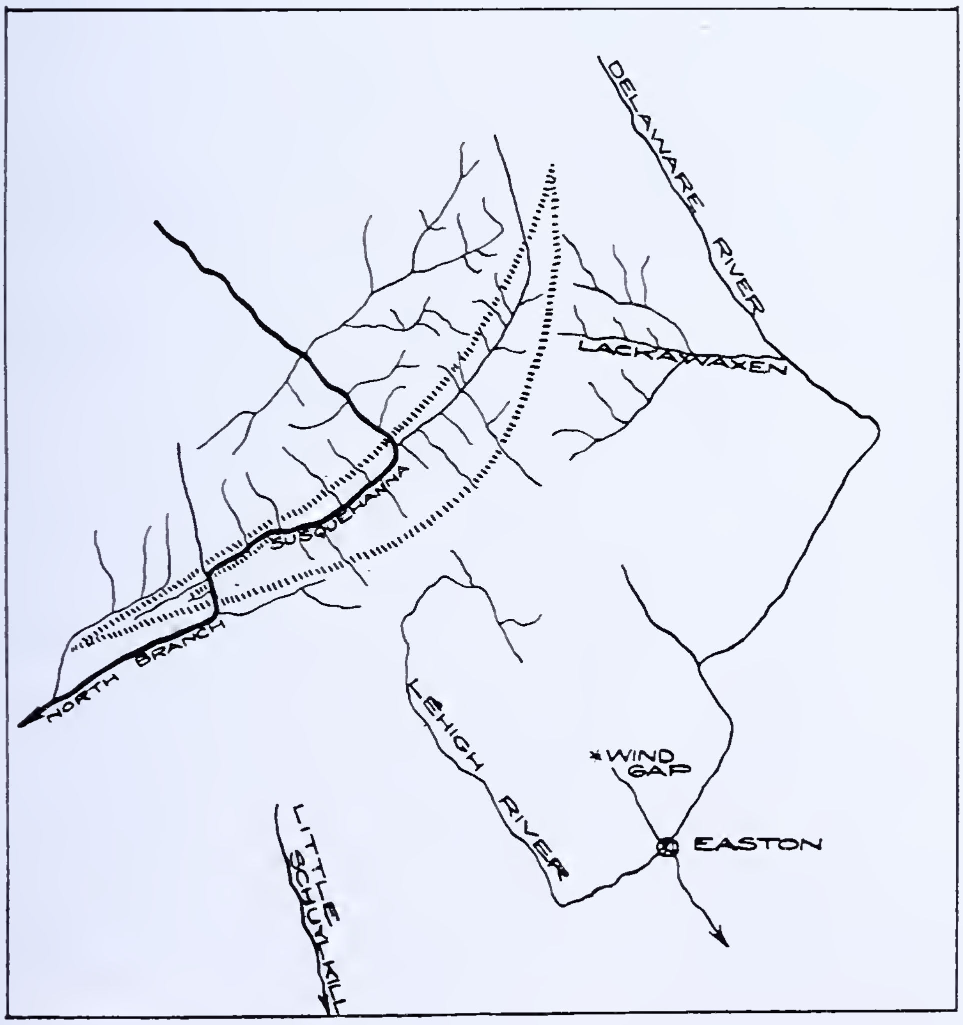

Figure 32. Present major drainage.

tween Hazleton and Berwick. While this pass does not necessarily represent a wind gap, it occupies the position where, under the theory of regional superposition, we should expect a wind gap. Diversion at a fairly early date in the Harrisburg cycle, with subsequent obliteration of true wind gap form, may well account for the present doubtful appearance of the pass.

Minor drainage features.—The evolution of the minor drainage ot the region differs markedly according to the hypothesis considered. The present location of the Lackawanna River in the east end of the basin is construed on the basis of the Davisian hypothesis as an original consequent flowing westward down the pitch of the syncline. (See Figure 24 A, B.) The minor centripetal streams in and around the basin are considered by Davis[7] as:

> ". . . consequents which originally ran down the enclosing slopes. These streams must have cut gullies and breaches in the hard Carboniferous beds and opened low back country on the weaker Devonian. Some of the existing streams still do so, and these are the ones not easily reached by divertors. The Susquehanna outside the basin has sent out branches that have beheaded all the centripetal streams within reach; where the river enters the basin the centripetal streams have been shortened if not completely beheaded. Near the eastern end of the basin the Delaware has captured the heads of some of the streams." (See Figure 28.)

According to the theory of the regional superposition from a coastal plain most of the major drainage must have crossed the region in a general northwest-southeast direction, and branches of the larger streams must have entered the main streams obliquely. (Figure 29.) With the development of types of drainage normal to a coastal plain, i. e., consequents, subsequents, resequents, and obsequents, these types were ultimately superimposed upon the underlying structure (See Figures 30, 31, and 32.) These streams were further modified by stream capture in ensuing erosional periods.

On this basis the streams which today enter the valley by breaching the northern rim may be supposed to have inherited their courses as the result of regional superposition of (1) original southeast-flowing consequents or their obliquely-flowing branches, and (2) resequents whose courses were established either on the back slope of a cuesta or on the stripped surface of the fold. The North Branch of the Susquehanna and Shickshinny Creek are regarded as examples of the former and Hunlock, Harvey, Toby, etc., may be examples of the latter. Streams entering the valley from the south (1) may have

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[7] William Morris Davis: idem, p. 249.

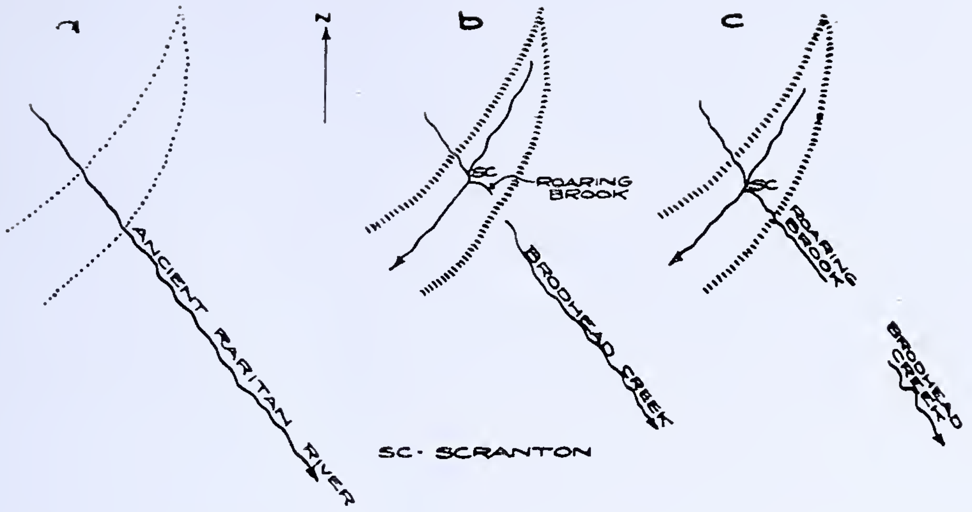
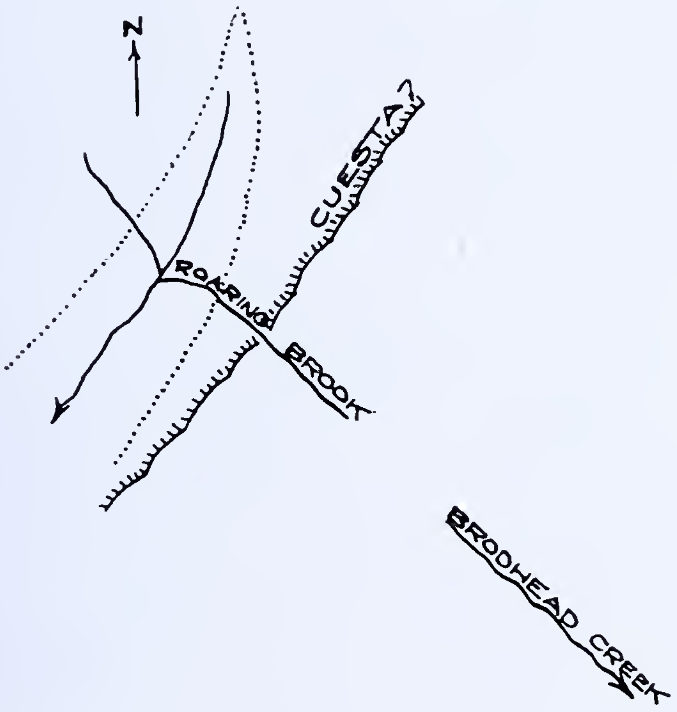
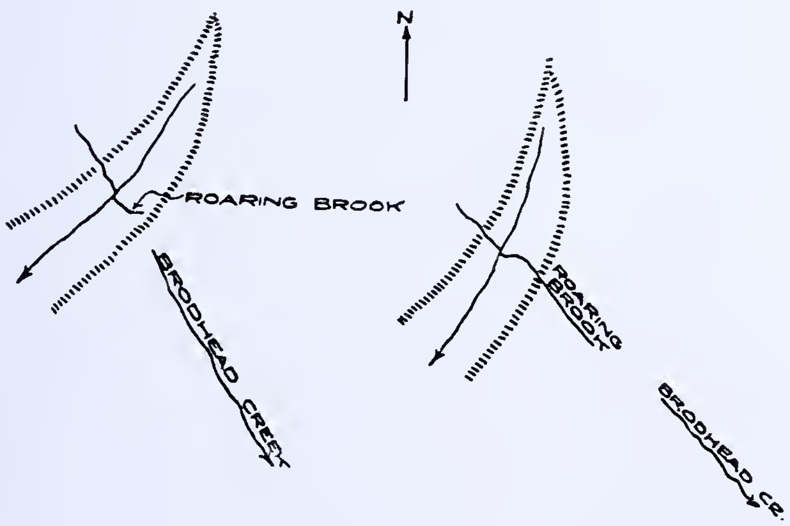


Figure 33. A. Roaring Brook as a remnant of original ancient Raritan drainage.



B. Roaring Brook as an obsequent developed on the coastal plain.



C. Roaring Brook as a resequent modified by glacial diversion.

developed obsequent courses on the coastal plain and inherited those courses through superposition; or (2) they may be resequents developed on the stripped fold; or finally (3) they may represent streams formerly flowing south across the Poconos which were in part diverted in Pleistocene time through glacial action. Examples of the latter type are Buttonwood, Stafford Meadow Brook, Roaring Brook, Spring Brook, etc. Of these streams Roaring Brook is the only one which clearly extends beyond the southern rim and as such deserves special consideration. The upper course of Roaring Brook, Brodhead Creek, and the portion of the Delaware River from Delaware Water Gap to Manunka Chunk are considered as probable former parts of original "Raritan" drainage on the coastal plain. At present Roaring Brook flows northwest into the valley. The possible interpretations of this course appear to be as follows:

(1) Roaring Brook may represent drainage along the route of the upper ancient Raritan. Capture of the upper Raritan at or about Scranton [Figure 33A (b)] in the Schooley or later cycles would give the condition shown in this figure. The lower part of Roaring Brook would then be resequent, flowing down the dip slope. At this stage conditions would be somewhat similar to the conditions noted at present to the northeast in the Lackawaxen-Delaware drainage. (See Figure 34.) Glacial diversion in the Pleistocene may have placed the divide at the head of Roaring Brook somewhat farther southeast [See Figure 33 A (c)], where extensive glacial deposits occur. The diversion would not be a difficult matter, for the Poconos and Moosic Mountains are practically the same level, whereas these conditions do not hold in the case of the Lackawaxen.

(2) As a second possibility Roaring Brook may be considered as an obsequent stream inheriting its present course from a similar position on the coastal plain. In this case the alignment with Clarks Gap, Brodhead Creek, and the Delaware River would have to be regarded as a matter of accident. Extensive modification during the various erosional cycles and particularly during the Pleistocene may well have removed any definite evidence pointing to an original obsequent mode of origin. (See Figure 33 B.)

(3) According to a third interpretation the portion of Roaring Brook within the syncline might be regarded as a simple resequent developed in the Schooley or later cycles, and the upper course as an addition due to glacial diversion. The upper course would then be

largely a matter of accident and no weight would be attached to the alignment of the drainage features previously mentioned. (Figure 33 C.)

The weight of evidence indicates that Roaring Brook represents a portion of the upper ancient Raritan. The diversion presumably took place in a later stage than the Schooley, thus giving the original stream an opportunity to develop the gap in the Moosic Mountains, which was utilized when the headwaters of Brodhead Creek were diverted northwest to become part of Roaring Brook.

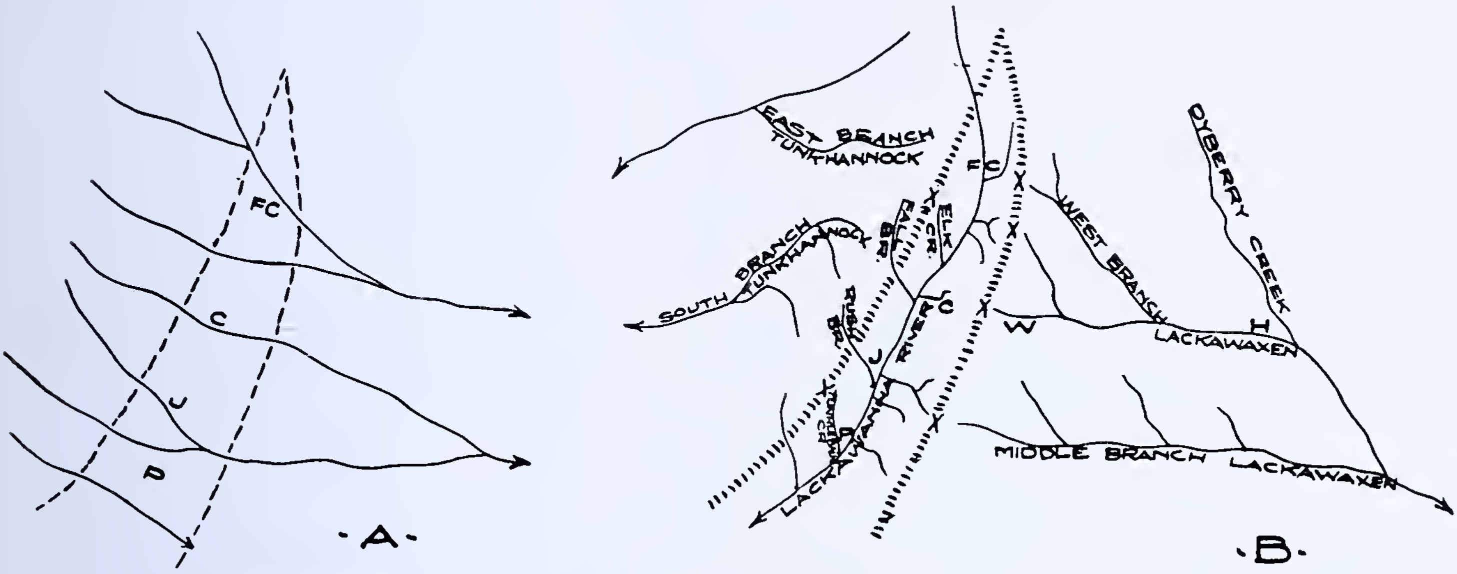


Figure 34. Lackawanna and Lackawaxen drainage.
A. Hypothetical original coastal plain drainage.
B. Present drainage.

Near the eastern end of the basin streams now represented by West Branch and Middle Branch of the Lackawaxen are regarded as remnants of either original southeast-flowing master streams or their branches which were later beheaded by subsequents developed by the Susquehanna. Evidence to support this view is found in the orientation of water and wind gaps on both sides of the syncline and their alignment with the present drainage. (Figure 34 A and B.)

The small streams which flow down the present slopes of the syncline but do not breach the rim are regarded as resequents developed during the Schooley or more recent erosional cycles.

SUMMARY OF DRAINAGE EVOLUTION

While many of the drainage features may be accounted for on the Davisian hypothesis, several of the major problems, particularly those relating to the position of the upper North Branch of the Susquehanna and the alignment of water gaps at Shickshinny, are difficult of interpretation on this basis. Probably the most significant fact concerning the Johnsonian theory of regional superposition as applied to this area is that it logically and adequately explains all the major drainage features while none of the minor factors are contradictory to it. It is therefore considered the more probable theory upon which to base the evolution of the drainage.

The original drainage relations which have given rise to the present stream systems are believed to be somewhat as shown on Figure 35. Since considerable modification has occurred in Tertiary time the original location of certain of the streams is necessarily assumed; in others the evidence seems to indicate that at least some remnants of the ancient drainage are in practically the same position as when initially developed, but at a decidedly lower level.

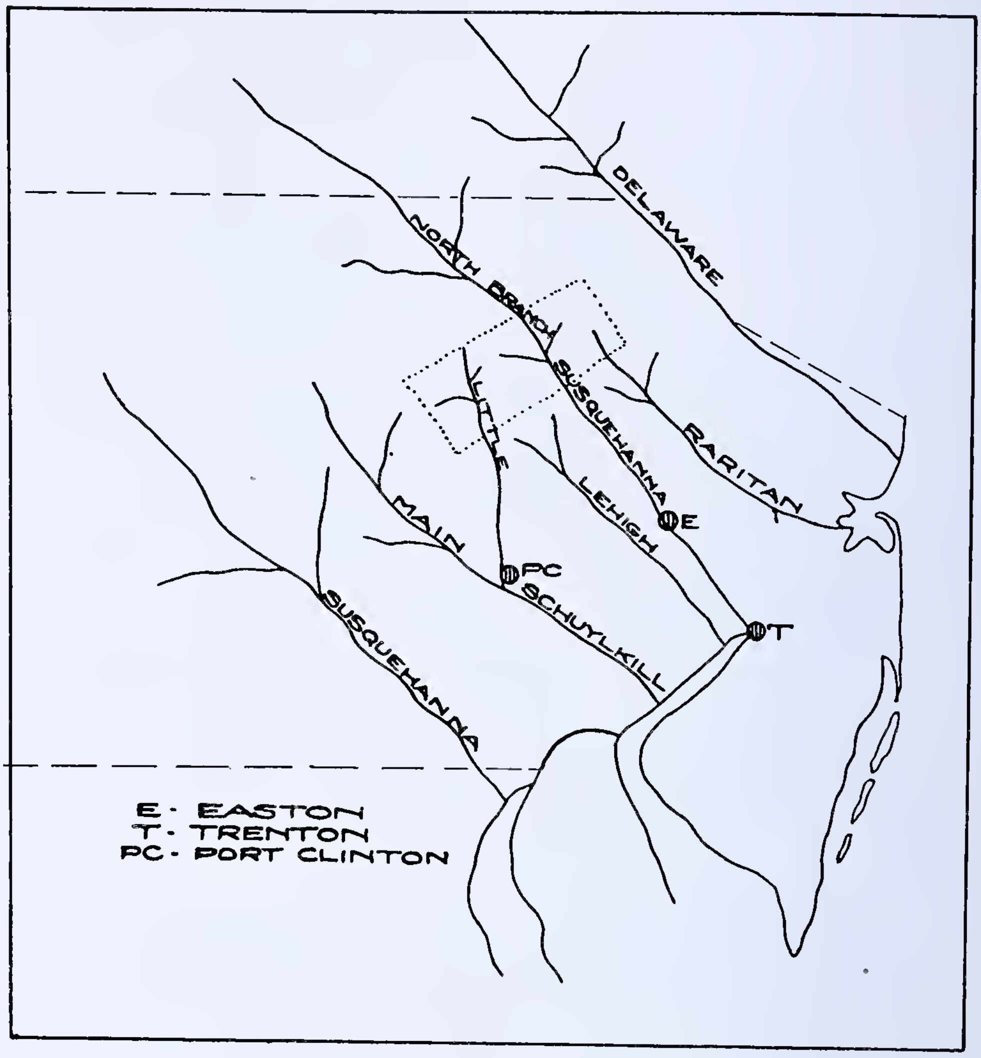


Figure 35. General type of drainage as developed in an early stage on the coastal plain.

The coastal plain on which the initial drainage developed is considered as of Cretaceous age, the sediments covering a peneplane completed during an earlier part of the Cretaceous period. (Figure 36.) During the Tertiary the initial consequent drainage is believed to have suffered considerable modification, with the development of subsequent drainage in either inner lowlands, intercuesta lowlands or both, and with the development of resequents and obsequents on the newly developed surfaces. These relations are shown in Figure 37.

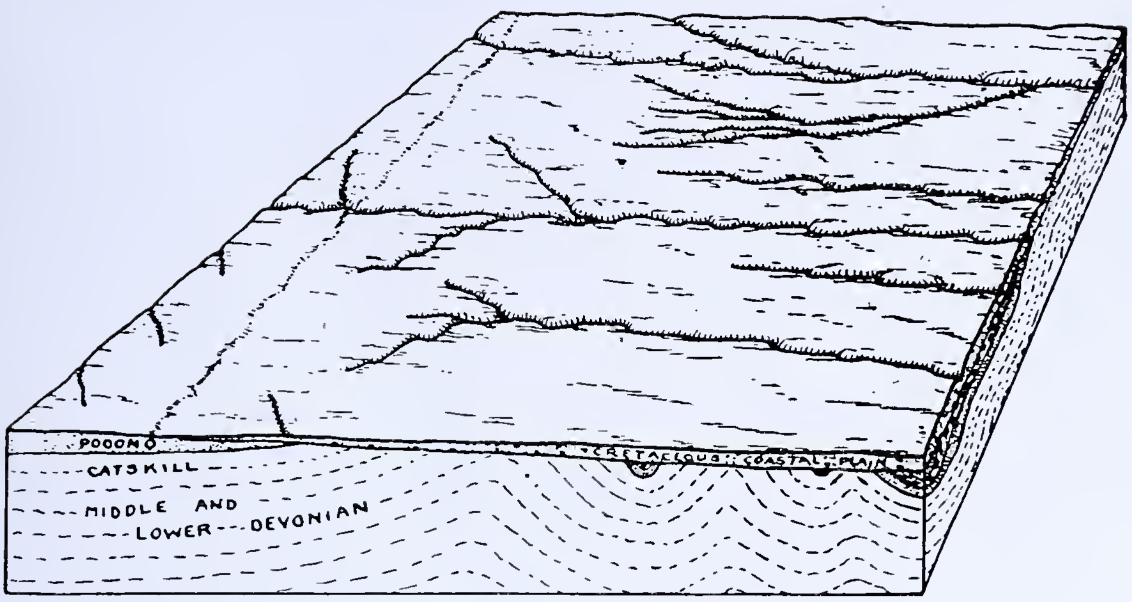


Figure 36. Hypothetical initial drainage on the coastal plain.

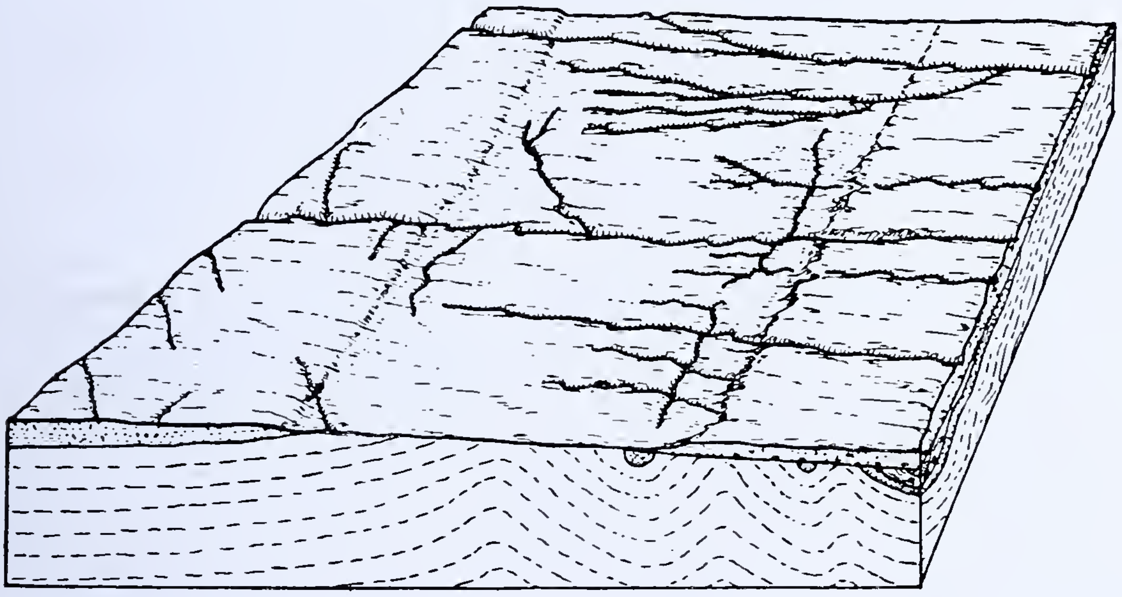


Figure 37. Modification of drainage and partial removal of the coastal plain.

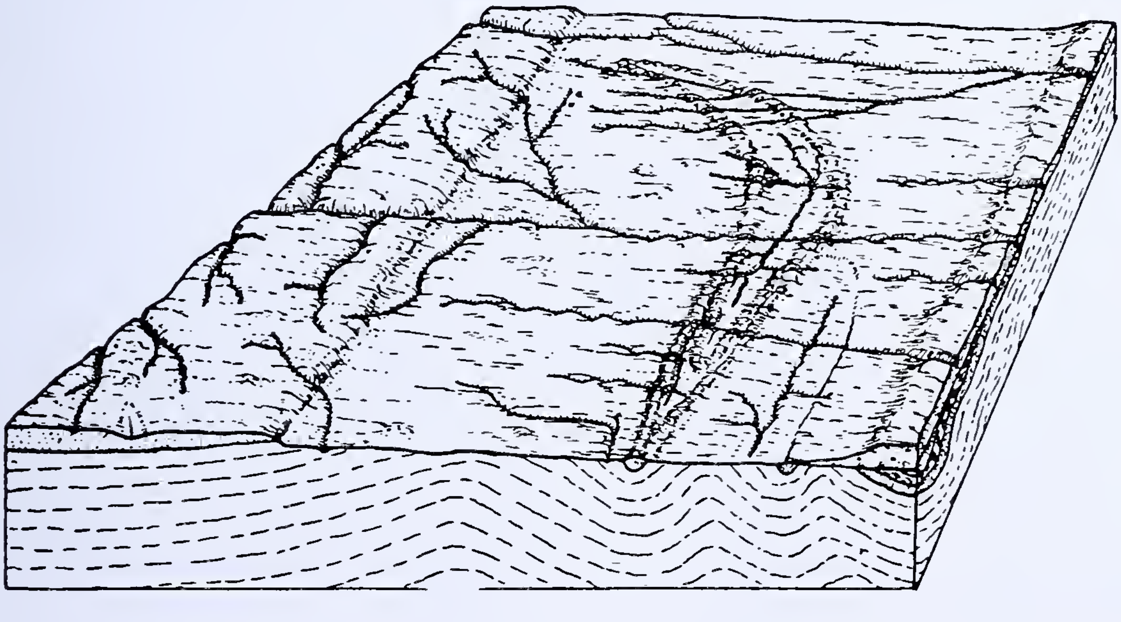


Figure 38. Removal of coastal plain and superposition of the drainage.

Further modification of the drainage must have taken place during the period required for the stripping of the coastal plain cover. With its removal the type of drainage developed previously must have been superposed on the underlying hard rock structure. (Figure 38.) Further serious modifications must have taken place under the guidance of the new structure. (Figure 39.) Continued erosion found the region passing through the various stages of the Schooley cycle, culminating in the development of the peneplane of the same name. The hypothetical drainage on the peneplane is thought of as approximating the conditions as shown on Figure 40. Evidence suggesting certain of the major changes believed to have occurred during the Schooley cycle are indicated below.

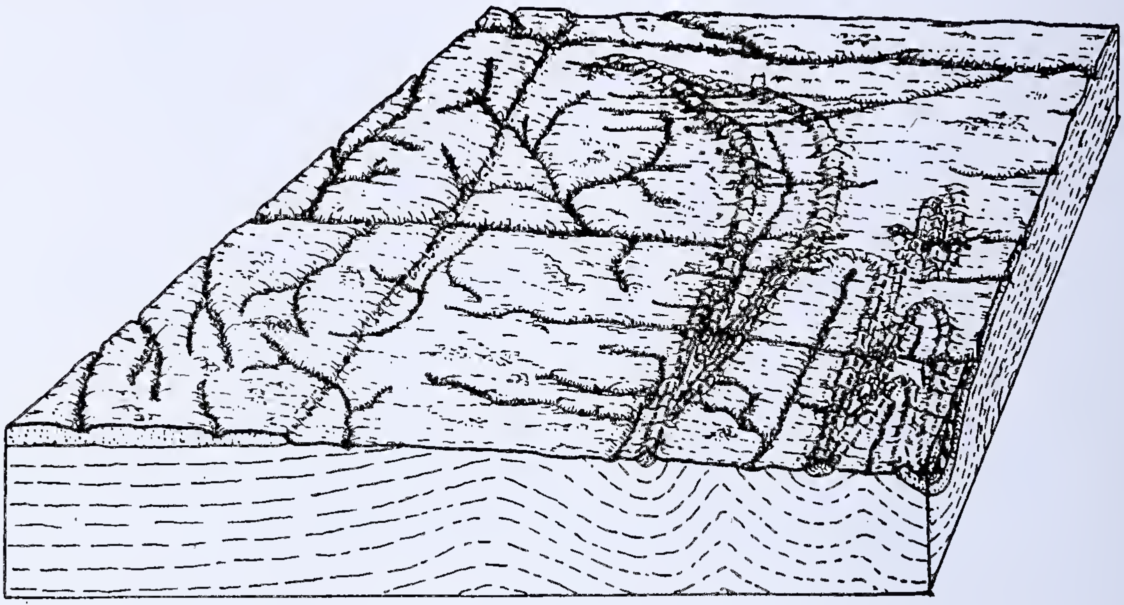


Figure 39. Hypothetical drainage during the Schooley period.

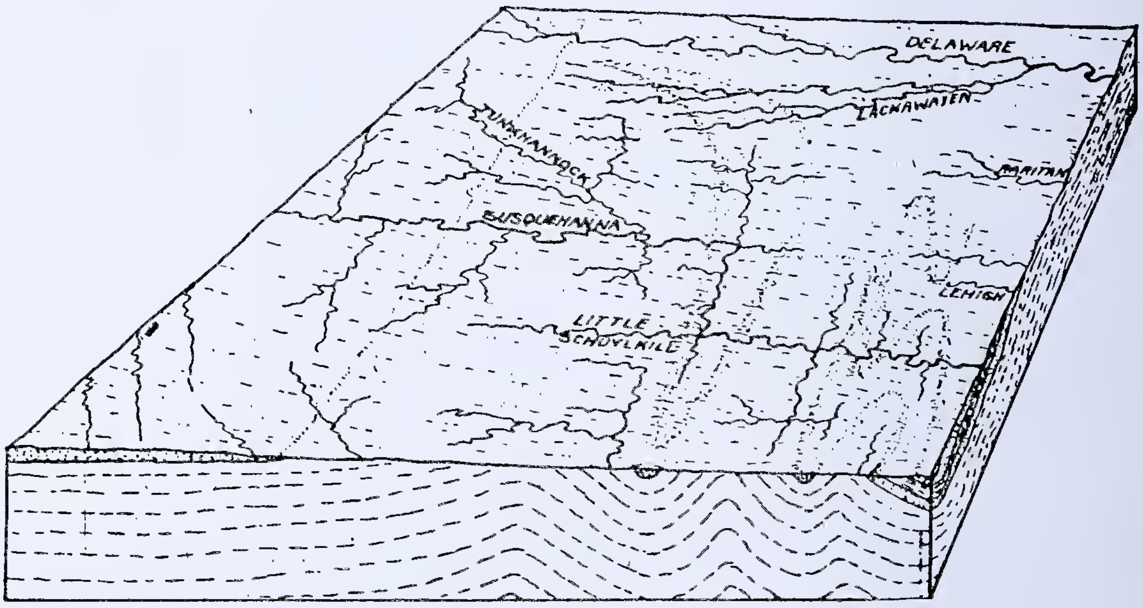


Figure 40. Hypothetical drainage on the Schooley peneplane.

The pass or wind gap in the Schooley surface as developed on Nescopeck Mountain suggests that the Little Schuylkill persisted in its southeastward course throughout the Schooley cycle. Lack of any pass or gap in the Pocono region aligned with the upper North Branch of the Susquehanna suggests the diversion of this stream during the same cycle. Superposition of the subsequent branch of either the Susquehanna or Little Schuylkill across the Pottsville ridge at Nanticoke appears to have occurred in this cycle since the ridge crest represents the Schooley surface. In the east end of the area several of the original streams now represented by Lackawaxen drainage apparently maintained southeast courses throughout the cycle as evidenced by the alignment of wind and water gaps on both sides of the valley. Ancient Raritan drainage may likewise have persisted throughout the Schooley cycle as indicated previously in the case of Roaring Brook.

During the Harrisburg cycle other important changes must have taken place. The diversion of the Little Schuylkill westward appears to have taken place early in this cycle if not at the very conclusion of the Schooley, as evidenced by the pass in Nescopeck Mountain. In this erosional period the headwaters of the ancient Raritan (Roaring Brook) and the ancient Delaware (Lackawaxen) were presumably captured by the Lackawanna, a subsequent of the Susquehanna, as evidenced by the wind gaps in the Moosic Mountains in the east end of this region. (See Figures 34 A and B.)

The present minor drainage has developed largely as a result of continued modification in later erosional cycles and in considerable part is due to glacial diversion.

POST-SCHOOLEY UPLIFTS AND DENUDATION

REMNANTS OF THE SCHOOLEY SURFACE

A series of projected profiles based on topographic maps of the area was constructed as a basis for study of the erosional surfaces. Two well-developed erosional planes and a third very locally developed were noted. These different surfaces indicate several periods of uplift and erosion, all of which have occurred within Tertiary or later time.

The Schooley or early Tertiary peneplane is represented in the region by partial preservation on the most resistant rocks of the region, the Pocono formation, and to a smaller extent on the Pottsville. In the immediate area the higher and older Schooley surface is represented by the mountains forming the rim. On the south and east side of the valley below Wilkes-Barre they rise to an elevation of 2000-2100 feet and maintain this general level northeastward, rising gently in that direction to a level of about 2300 feet. This 2000-2300 feet undulating surface occurs also on the northwest side of the valley above Old Forge-Duryea. The continuity of the upland area is broken somewhat by the development of wind and water gaps. In general there is a gradual slope towards these gaps in the northwestern part of the area, suggesting that the wind and water gaps inherited more ancient courses across the mountains.

Southwest of Wilkes-Barre on the south side of the valley and below Old Forge-Duryea on the north side of the valley remnants of the Schooley peneplane are missing except at the extreme southwestern end where Lee and Huntington Mountains meet. Otherwise the Pocono and Pottsville ridges in this part of the region are considerably below the presumable present level of the Schooley peneplane. The mountain rim in this section rises to elevations of 1400-1600 feet, far below the level of the Schooley to the northeast. The Pocono and Pottsville ridges are thus residuals standing above a lower erosional level but by no means representative of the higher and older Schooley.

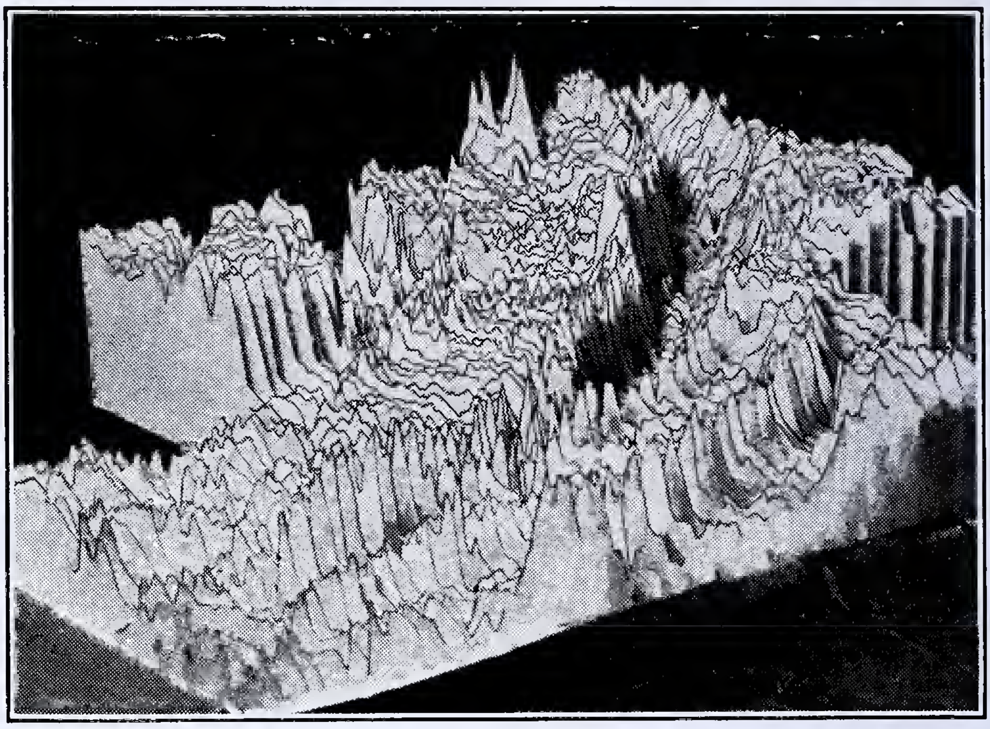


Plate 5. Photograph of projected profiles of the Wyoming-Lackawanna region. Profiles run northwest-southeast. Photograph views model as from the southwest.

Study of geologic maps and structure sections for the southwestern area makes clear why the hard Pocono and Pottsville ridges fail to represent the Schooley surface here, whereas to the northeast they do. If the Pocono and Pottsville formations were considerably thicker in the northeastern end of the region the reason for the higher Schooley level there might be obvious. However, it happens that the Pocono is thinner in the northeast than in the southwest, being about 400 feet in the neighborhood of Scranton whereas it is at least twice that in the southwestern part of the area. The Pottsville formation changes little in thickness throughout the region. The explanation, therefore, cannot be based on the variable thickness of the resistant rock. The weak Mauch Chunk formation, which lies stratigraphically between the Pocono and Pottsville, also thickens toward the southwest. As a result of the thickening the two harder layers are separated, towards the southwestern end of the basin, by a valley eroded in the Mauch Chunk shale. Thus here each hard formation in the twin rim must stand on its own merits and can lend little support to the other. Streams cut deeply between the hard layers, making each ridge more susceptible to erosion and weathering. The opposite is true towards the northeast. There the Mauch Chunk is almost entirely missing, permitting the Pocono and Pottsville to unite essentially as one very thick resistant unit.

Again, while the Pocono thins toward the northeast, it provides a more resistant obstacle to erosional processes by flattening out somewhat on both the northwest and southeast sides of the valley. It thus exposes a much greater area of hard rock to the elements than does the more steeply dipping portion of the same formation in the southwest. The projected profiles show a bench two to four miles wide, developed on the Pocono sandstone, sloping gently southwest on the north side of the Lackawanna or Bald Mountains. This stripped bench, although no peneplane level in itself, has provided a wide area of resistant rock, thereby slowing down the reduction of the protected mountain rim. This is true to practically the same extent on the south side of the valley. There the gently dipping Pocono beds in the Pocono Mountain region have prevented any appreciable lowering of the Schooley surface. Northeast of the Pocono Mountain area the rim is protected as it is on the northwest side.

A third reason why the Schooley peneplane is not represented by the Pocono ridges in the southwest is found in the earlier history as developed in the section relating to drainage. The North Branch of the Susquehanna, flowing over the Pocono plateau was unable to cut through the bedrock and lower its course at the same rate as the Middle Susquehanna farther west. The latter, rapidly growing by assimilating numerous streams, worked into the southwestern portion of the area and began to reduce it while the North Branch still labored to saw its course through the Poconos. Thus during the erosional stage known as the Schooley cycle, the Middle Susquehanna (or Little Schuylkill) had entered the southwestern portion of the region and vigorously attacked it.

As a result of these three factors the Pocono ridges in the southwest were rapidly cut below the Schooley level in ensuing erosional periods while the Pocono formation to the northeast maintained the higher surface.

THE HARRISBURG CYCLE

The Schooley peneplane was ultimately uplifted, initiating a new erosion cycle which resulted in the production of a new erosion plane, the Harrisburg, covering extensive areas in the Appalachian region. The Harrisburg peneplane (Allegheny of the Pennsylvania Geological Survey) is the best preserved erosion level in the region. North of the Wyoming-Lackawanna Valley there is a strip, 10-12 miles wide, of gently rolling country, here and there dissected by streams which have cut narrow valleys 300 feet or more below the general level. The strip may be divided into two portions, one northeast, the other southwest of the North Branch of the Susquehanna. The northeastern section lies about 600 feet above the river level close to the river and rises gently toward the northeast, reaching an elevation of about 1400 feet in the country south of Elk Mountains. The region is best described as rolling country interrupted by the development of a number of deep stream valleys, such as have been cut by Tunkhannock Creek and its numerous branches. These valleys are cut to a depth of 300-400 feet below the surrounding upland peneplane. The country lying between the forks of Tunkhannock Creek and the East Branch of the creek is a good example of the Harrisburg peneplane. Here the elevation is about 1400 feet. The general slope southwest to the Susquehanna results in a gradual drop to about 1200 feet in a distance of about 21 miles. The Susquehanna has cut far below the level here mentioned, the river flowing at an elevation of 600-700 feet. This would give a 200-foot fall in the peneplane surface in a distance of 20 miles, or about 10 feet to the mile. Above the general level of the peneplane numerous areas stand out locally as higher eminences. Some of these may reach elevations of 1600 feet but stand up only as local residuals.

Southwest of the upper North Branch of the Susquehanna the Harrisburg peneplane displays features similar to the northeastern section. The peneplane slopes rather abruptly toward the Susquehanna, dropping from an elevation of about 1400 feet to 1200 feet in a distance of 5-6 miles. This would give a slope of about 40 feet to a mile in a northwest direction. To the west of Center Moreland the peneplane again slopes toward the southwest and away from the river. In a distance of about 33 miles the peneplane slopes from 1400 feet to an elevation of about 1000 feet, or approximately 12 feet per mile. This is nearly the same slope as recorded for the area northwest of the Susquehanna. The general slope of the peneplane is indicated in the diagram. (Figure 41.)

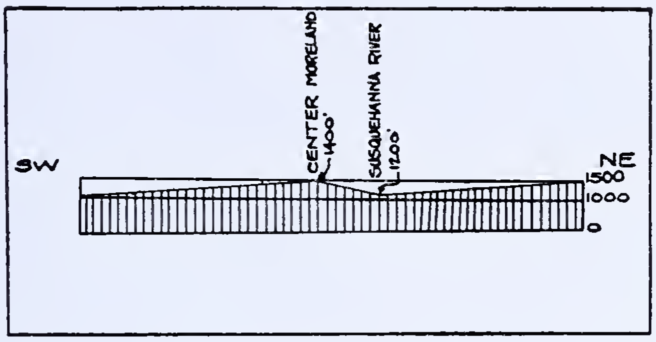


Figure 41. Slope of Harrisburg peneplane in area north of Wyoming-Lackawanna region.

Perhaps the simplest explanation of this interruption of slope is to consider the present inequality of slopes as due to the migration of a divide caused by gentle tilting toward the northeast. On any peneplane we should expect to find the interfluve areas somewhat higher than the stream valleys themselves. In general we should expect areas sloping gently from the divide toward the river. In this area the character and structure of the rock would have comparatively little to do with control of low divides on a peneplane. If such a peneplane were to be gently tilted toward the northeast, streams flowing in the opposite direction would be strengthened and the divide would tend to migrate towards the axis of the uplift, that is towards the northeast. In this case it would result in a migration of the divide northeast toward the Susquehanna with the consequent steepening of slope on the southwest side of the river and the development of the profile as shown on the above figure.

Two other areas adjacent to the Wyoming-Lackawanna Valley are believed to represent the Harrisburg level. These areas lie to the east and to the south of the region and are separated by the Pocono Mountains. The first area lies to the east of the northeastern part of the valley. The largest town in this section, Honesdale, is situated in the valley of West Branch of Lackawaxen River and Dyberry Creek at an elevation of 860-900 feet. The general upland level in this vicinity stands at about 1500 feet, as in the vicinity of Bethany, 4 miles northeast of Honesdale. In the vicinity of White Valley and Cold Spring 11 miles northeast the level is about 1600 feet. This indicates an average slope of about 10 feet per mile rising towards the northeast and agrees with the slope on the opposite side of the Wyoming-Lackawanna Valley. The Honesdale section of the Harrisburg peneplane is tributary to the Delaware River rather than the Susquehanna. This level joins the Harrisburg level as developed west of the valley in the region north of the Moosic Mountains and evidently constitutes the major erosional level as seen in the extreme northeastern part of the State.

The second area of the Harrisburg surface is west of the Pocono Mountains in the region southwest of Wilkes-Barre. It lies in a broad cove between Penobscot Mountain on the north, the Poconos on the east, and Nescopeck Mountain on the south. West of the Susquehanna it occupies a restricted area hugging Lee Mountain on the north and Penobscot on the south. The level is best shown in the cove drained by Pond, Little Wapwallopen, and Wapwallopen creeks, and east of the Susquehanna covers an area of about 100 square miles. The elevation at the east end of the cove is about 1250 feet and drops to about 1000 feet at the Susquehanna. The steep bluffs which rise some 500 feet above the Susquehanna in the vicinity of Pond Hill Station, Wapwallopen, and Nescopeck are the result of the river cutting below the Harrisburg level in post-Harrisburg time. A considerable portion of the old Harrisburg level has been preserved except where the streams mentioned have cut valleys below the level. An excellent view of this level may be obtained from the new State Highway from Wilkes-Barre to Hazleton. From the summit of Nescopeck Mountain the gently rolling surface of the cove stands revealed as an erosion plane some 600 feet lower than the mountain. The peneplane level in this area agrees in elevation with the Harrisburg level north of Shickshinny Mountain, and presents a picture of the landscape of the Wyoming-Lackawanna Valley at the time of completion of the Harrisburg erosion surface.

The level inside the valley must have been about the same as in the Wapwallopen area to the southwest. It could hardly have been lower, for the Susquehanna was then flowing over the Harrisburg surface in the vicinity of Wapwallopen at what is now 1100 feet elevation. It could not have been much higher, for the Harrisburg level northwest of the valley is not much higher than to the south. When the Harrisburg peneplane had reached its maximum extent the Wyoming Valley was definitely shaping into its modern form.

At the completion of the peneplane certain of the major features in and about the present valley had assumed a modern character. The erosional level could not have been more than a few hundred feet above sea level at most. Some 600 feet above this gently rolling surface arose the mountains which today encircle the valley. The upland level presented by these ridges, remnants of the Schooley erosional surface, must have been much more regular and uniform than the present level. In the lower southwestern portion of the region the twin rim surrounding the valley had been partially etched, although the valley developed between the two hard layers had by no means reached its present gorge-like aspect. The ridges, protected to lesser degree than those farther northeast, had already been lowered somewhat below the Schooley level but stood above the Harrisburg surface as well-developed mountains. In the area adjacent to Harvey Lake, northwest of Wilkes-Barre, a group of residual hills arose 200-300 feet above the Harrisburg, but were hardly remnants of the Schooley surface. Reduction of these hills to a peneplane was checked by lithologic and structural features. The structure here is synclinal, the rocks are hard sand members of the Catskill and presented a resistant front to erosional forces.

The Harrisburg level in the Wyoming-Lackawanna Valley must have extended originally from west of Shickshinny to about Carbondale. Above the latter point the hard Pottsville formation must have withstood the erosional attack somewhat better than the softer measures in the wider valley to the southwest and remained above the Harrisburg level. Several minor areas within the valley appear to constitute remnants of the Harrisburg surface. These areas are generally slightly lower than the Harrisburg level at the present time, due largely to the fact that they have been developed on less resistant rocks and lie in a region where erosional forces are concentrated. One of the best examples is the nearly flat area between Jermyn and Peckville. This section has a nearly uniform level of about 1200 feet and rises some 300 feet above the Lackawanna River. Several small local areas between Peckville and Scranton on both sides of the river rise to elevations of about 1100 feet, as in the area south of Throop. Nay Aug Park in Scranton and a portion of western Dunmore appear to lie on this same general erosional surface. Between Scranton and Moosic and in the hilly area east of Avoca numerous hills have a general accordant level of 1000-1100 feet. Local areas west of Glen Lyon in the southwestern portion of the valley have flat erosional surfaces reaching the same elevation as the Harrisburg level beyond the mountain rim on the south. The hills immediately south of Shickshinny, made up of Pottsville rocks, have levels coinciding with the Harrisburg both above and below the higher Pocono rim.

Many flat areas in the valley expose bedrock near the surface. In some cases the surface is horizontal because the rocks themselves lie nearly flat and with normal erosion will tend to maintain a stripped structural surface. Where such areas may coincide with the Harrisburg level outside the valley they may rightly be considered as peneplane remnants. There are very many places in the valley, however, where the rocks flatten and develop stripped surfaces. Where the levels are materially above or below the Harrisburg level they are treated as stripped plains or benches. The undoubted cases of peneplane origin are those areas in which the rocks have a fair degree of dip or inclination and those dipping beds have been definitely beveled. Many of the flatter areas above the present lower valley level are to be regarded as structural benches and are not indicative of any specific erosional level.

Relation of Harrisburg level to rock character.—Whereas the Schooley peneplane surface is preserved generally on the Pocono and to a minor extent on the Pottsville formation, the Harrisburg level has been developed on practically all the other rocks in the region. Northwest of the valley the level was developed on rocks of Devonian age, chiefly the upper or Catskill series. These rocks are largely sandstones, generally thin-bedded, with some shales and are inferior to the Pocono and Pottsville in ability to withstand erosion, but are by no means soft or easily eroded rocks. In the region north of Shickshinny, Devonian rocks lower in the geologic time scale than the Catskill are exposed. These are mostly thin-bedded sandstones and shales, certain of the beds being considerably harder than others. Structurally these beds strike from northeast to southwest, developing a gentle anticline between the Wyoming-Lackawanna area and the North Mountains.

The Honesdale portion of the Harrisburg surface is developed almost entirely on rocks of Catskill age. For the most part the beds dip very gently but with no highly developed folds. In the area southwest of the valley the Harrisburg surface is developed on the Catskill and Lower Devonian rocks. Structurally the cove is an anticline, the rocks originally arching high above the region. Thus the Catskill beds south of the Penobscot Mountains at one time arched high over the center of the Wapwallopen area and came down on the north side of Nescopeck Mountain. Most of the hills in the cove today represent harder layers in the Catskill and Lower Devonian formations which have not been cut below the Harrisburg level.

In the Wyoming-Lackawanna Valley, synclinal in character, the Harrisburg surface was developed on rocks of Pennsylvanian age, known as the Coal Measures. These beds consist of a series of sandstones, shales, coal, and "slate." Taken as a unit they are softer and more easily eroded than either the Catskill or Lower Devonian formations and generally form a weak group of rocks. Certain individual beds may stand out as considerably superior to the group as a whole, and it is these beds which have preserved the hilly areas in the valley.

It will be seen that the Harrisburg peneplane was developed on rocks of different character, different ages, and different structure. Rocks of Catskill, Lower Devonian, and Coal Measure formations, anticlines, synclines, and areas of gently dipping rocks, areas within and behind hard Pocono barriers, all alike were leveled. Thus the Harrisburg level must have extended over a considerable area in the east, failing to reduce only the very hard Pocono and to a lesser extent the Pottsville formations.

POST-HARRISBURG UPLIFT

In late Tertiary time an uplift of about 300 feet re-established the vigor of streams which had become somewhat sluggish on the Harrisburg surface. A new erosional level, the Somerville, was produced locally, standing at an elevation of about 750 feet and usually appearing as a rock bench along the banks of the main stream. Apparently the streams had comparatively little time to expand this new erosional surface for before it had developed over any considerable area a new uplift checked it. It is represented in the southwestern portion of the area by the bench 2 or 3 miles wide paralleling the north bank of the river between Mifflinville and Bloomsburg. Toward the northeast the bench has been covered with outwash from the glacier. Here the peneplane has been developed on Lower Devonian sandstones and shales.

In the valley itself the Somerville peneplane is not represented by any extensive surface. The softer sandstones and shales of the valley yielded considerably in the Somerville period of erosion while the harder rocks about the valley apparently were hardly affected. Between Glen Lyon, Nanticoke, and Wilkes-Barre many hills reach an accordance of summit level of 700-800 feet, most of them about 760 feet. Between Wilkes-Barre and Pittston several flat-topped hills are developed on inclined strata, as at Midvale, east of Miner's Mills, Plains, Port Griffith and Pittston. The hill immediately to the north of Pittston is apparently a remnant of this surface. A portion of the area around Barbertown reaches a level of about 760 feet and is developed on inclined strata. Northeast of this region terraces occur at varying levels and appear to be structural rather than erosional. There seems to be no development of the Somerville surfaces along the Susquehanna northwest of Pittston. Inasmuch as the Somerville is developed only to a minor extent in the region immediately to the southwest of the valley we should hardly expect to find the level developed to any considerable extent above the barrier of the Pocono ridges.

CONCLUDING UPLIFT

An uplift of 200-250 feet interrupted the development of the Somerville cycle and resulted in the development of deep narrow stream valleys throughout much of the area covered by the Harrisburg peneplane. The Susquehanna and its major branches north of the valley have incised themselves in deep gorges far below the Harrisburg surface. In the southwestern part of the region the Susquehanna flows at an elevation slightly below 500 feet above tide while the Harrisburg surface, which ends in a bluff at the river's edge, as at Pond Hill Station and Wapwallopen, stands at an elevation of about 1050-1100 feet. The amount of uplift in this section of the area since the completion of the Harrisburg peneplane is thus 550-600 feet.

The landscape at the conclusion of Tertiary time, following the uplift of the Somerville surface (and all older surfaces) and after the present valley deepening, would be essentially what we should see today, had it not been that at the conclusion of Tertiary time a new geologic period was inaugurated by the coming of great sheets of ice which during the Pleistocene further changed the pre-existing landscape.

PROBLEMS OF THE PLEISTOCENE

ORIGIN OF THE BURIED VALLEY OF THE SUSQUEHANNA

The buried valley of the Susquehanna River and associated buried channels of the region present an interesting problem. The depression is not an ordinary valley with continuous slope, but as indicated in Figure 42 contains numerous elongated rock-rimmed troughs and basins between rocky ridges. Previous workers have suggested that the ancient valley was carved by simple stream erosion, but found great difficulty in harmonizing that hypothesis with the probability that the rock floor is at no great depth below the present river bed a short distance below Nanticoke (N on Figure 44). While this is in part surmised the fact remains that ledges cross the river some

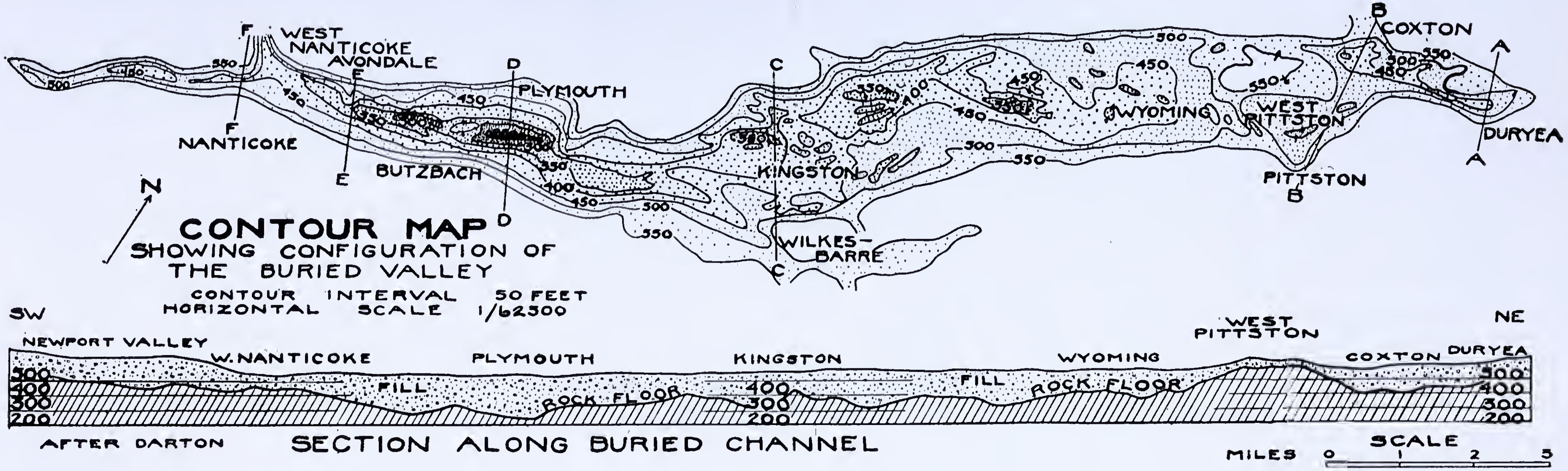


Figure 42. Contour map showing configuration of the Buried Valley of the Susquehanna. (Modified after Darton.)

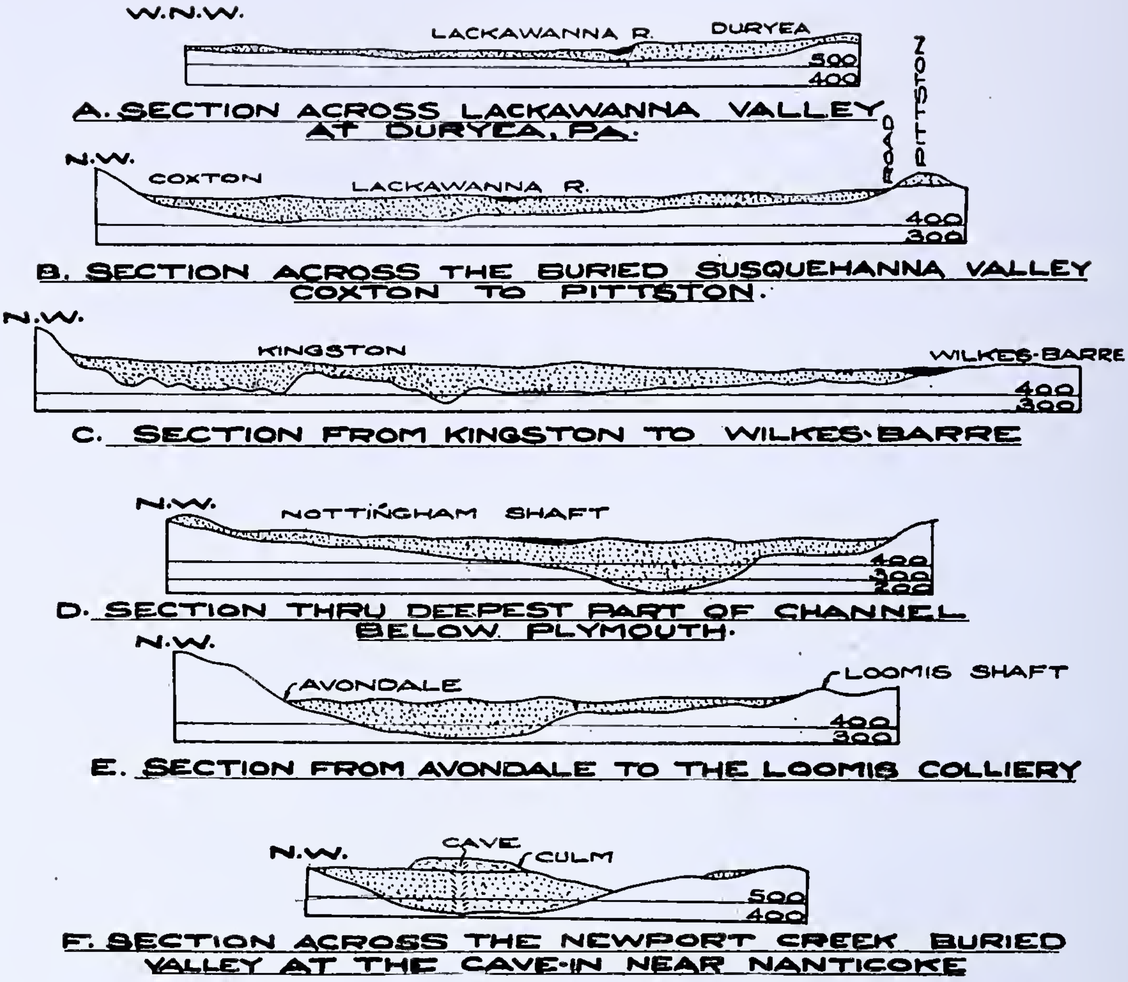

W.N.W.
LACKAWANNA R.
DURYEA
500
400
PITTSTON
ROAD
A. SECTION ACROSS LACKAWANNA VALLEY AT DURYEA, PA.
N.W.
COXTON
LACKAWANNA R.
400
300
B. SECTION ACROSS THE BURIED SUSQUEHANNA VALLEY COXTON TO PITTSTON.
N.W.
KINGSTON
WILKES-BARRE
400
300
C. SECTION FROM KINGSTON TO WILKES-BARRE
N.W.
NOTTINGHAM SHAFT
400
300
200
D. SECTION THRU DEEPEST PART OF CHANNEL BELOW PLYMOUTH.
N.W.
AVONDALE
LOOMIS SHAFT
400
300
E. SECTION FROM AVONDALE TO THE LOOMIS COLLIERY
N.W.
CAVE
CULM
500
400
F. SECTION ACROSS THE NEWPORT CREEK BURIED VALLEY AT THE CAVE-IN NEAR NANTICOKE

Figure 43. Sections across the Buried Valley. (Modified after Darton.) (For location of sections see Figure 42.)

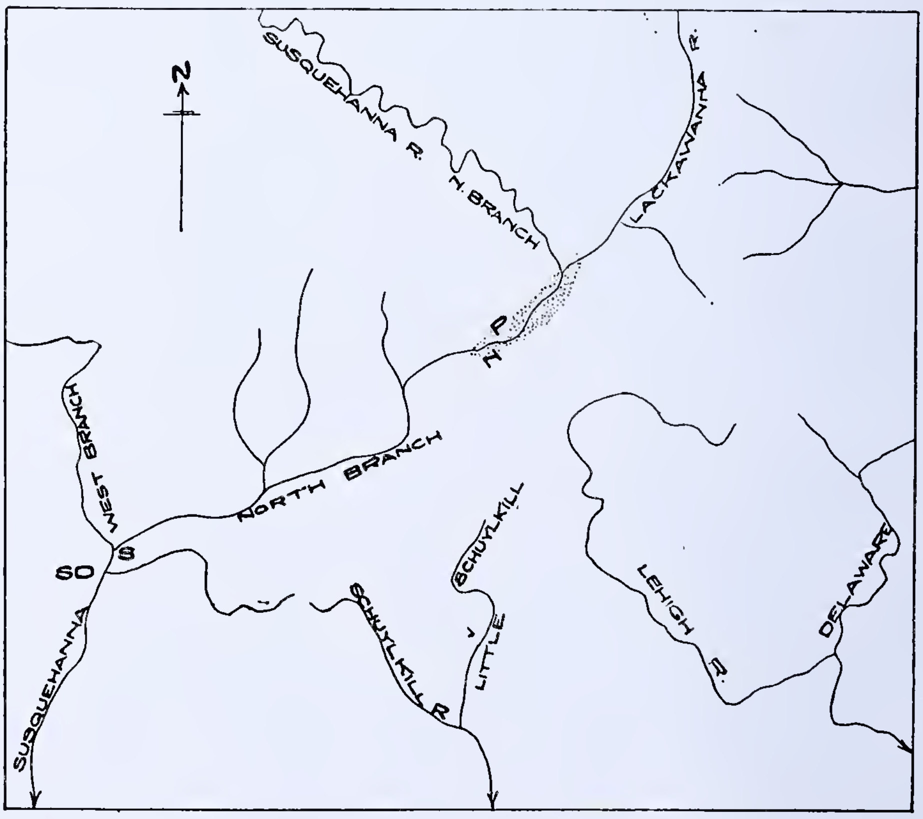


Figure 44. Regional relations of the Buried Valley of the Susquehanna.

miles to the southwest at a higher elevation than the rock floor at its deeper points in the valley. As far down the river as Shamokin Dam (SD on Figure 44), below Sunbury (S on Figure 44) a ledge of

Hamilton sandstone crosses the river at an elevation of about 428 feet. At Plymouth (P on Figure 44) the deepest bore-hole shows rock bottom at a depth of 309 feet below the surface. The surface elevation at this bore-hole is 536 feet. Thus the bottom of the old buried valley at Plymouth some 70 miles upstream from Shamokin Dam is only 227 feet above tide, or about 200 feet below the rock ledge at Shamokin Dam. It is this peculiarity that has been so difficult to explain.

Corss[8] attempted to account for the overdeepening of this section of the Susquehanna's course by deformation of an ordinary river valley since the valley was developed. The great number of small depressions and ridges seem to preclude the possibility of deformation satisfactorily accounting for the feature observed.

Darton[9] has suggested that when the glacier advanced diagonally southward across the valley it probably picked up a large amount of soft material from the valley bottom. During this stage and later, streams flowing beneath the ice would have a tendency to deepen somewhat such holes and basins in the valley bottom. Thus he believes the basins and troughs were largely excavated by the ice itself.

The direction of the glacial striæ on the lower mountain sides shows that an ice tongue or tongues must have worked along the strike of the valley. While the main mass of ice moved diagonally across the valley, the ice in the lower portion was deflected along the valley axis. In waning stages when the ice had melted from the mountain tops all the ice in the valley would move parallel to the valley axis. This movement must have resulted in a plucking and gouging action with resultant development of troughs and holes in the soft materials of the valley bottom.

While it is believed that the glacier undoubtedly plucked a considerable amount of material from the valley bottom it is also believed that subglacial streams performed much more work than they are ordinarily credited with having accomplished. A considerable portion of the overdeepening of the valley may have been the work of streams flowing beneath the ice. The Mississippi River, in the stretch below Forts Jackson and St. Philip, reaches a depth of 186 feet at the bends, while 6 miles south the same volume of water passing through a cross section only about one half as large, and hence having double the mean velocity, has developed a channel only one-third as deep (60 feet).

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[8] F. Corss, Buried Valley of Wyoming: Wyoming Historical and Geological Society, Proceedings, vol. VIII, 1904, pp. 42-44.

[9] N. H. Darton, Some Features of the Quaternary Deposits in the Wyoming Region: Wyoming Historical and Geological Society, Proceedings, vol. XIII, 1914, pp. 41-64; see p. 63.

Large streams flowing under ice might still more irregularly deepen their courses. The conditions under which such streams work differ from the conditions under which normal surface streams work in an ordinary open valley. These subglacial streams must have flowed at times in highly restricted channels: restricted not only by the rock of the channel but also by the mass of ice overhead. Furthermore, because of crevassing and fracturing of the ice the streams may have been turned and twisted many times even in short distances, and have frequently developed powerful downward cross currents. Again, movement and shifting of the ice meant shifting of the subglacial channels, with the establishment of new sets of conditions. Finally, the main subglacial currents in the valley may have been under great hydrostatic pressure. Confined to tortuous and restricted quarters, they must have acted powerfully on the valley floor. As this process was repeated over and over again certain portions of the valley were deepened much more than others.

The other buried valleys of the region must have originated in much the same manner as the Susquehanna buried valley. Later a great amount of sand and gravel was brought into the valley in the waning stages of the glacial period and since that time. The filling of the valley seems to continue at the present time, for occasionally during periods of floods a sheet of mud is deposited on the lower lands bordering the river.

GLACIAL TERRACES

Introduction

The Wyoming-Lackawanna Valley is bordered by a series of more or less continuous terraces varying from a few feet to 130 feet above the present river level. The terraces vary in nature from rock terraces developed at higher levels to depositional forms at lower levels. In extent they vary from narrow discontinuous fringes to broad plains a half mile or more in width, as at Pittston and Larksville. These depositional terraces are considered as evidence that water levels considerably higher than the present must have existed in the valley at least during the later stages of the Glacial period. While suggesting higher water levels, the terraces' form, distribution, composition, and structure indicate that the processes which resulted in their development were complex.

Description of the Terraces

Rock Terraces

The 820-foot terrace.—A portion of the divide between Ascension Brook and the Lackawanna River in the vicinity of Old Forge and Rendham flattens out at an elevation of about 820 feet and forms a terrace. Coal mining operations in the vicinity show the terrace to be developed on a rock bench thinly covered with till. The surface of the terrace is generally smooth with no pronounced irregularities and no distinct terrace front, the upper surface gradually merging with lower surfaces near the stream valleys while towards the northeast it grades gently upward into the higher irregular surface near Taylor. The terrace is interpreted as a till-covered stripped structural plain, the level possibly representing the former Harrisburg level in this region.

The 765-foot terrace.—A second rock terrace having an elevation of about 765 feet is similar in general character to the 820-foot terrace although the latter is developed over a much smaller area. The terrace comprises the summit levels of the hills between Pittston and Duryea, between Duryea and Moosic, and the lower rock bench in the vicinity of Old Forge. The surface of the terrace is gently rolling and is covered with a relatively thin sheet of till. There is no distinct terrace front, the flatter hilltops sloping gently to the lower surfaces. In this section of the valley the coal measures have a very low dip and the nearly horizontal hilltops evidently represent stripped surfaces. Because of their proximity to the river and because they have been smoothed off somewhat with till, the general appearance is similar to the depositional terraces which lie at lower levels.

Depositional Terraces

The 745-foot terrace.—None of the terraces at levels below 760 feet are developed on rock. The highest of the depositional forms is the 745-foot terrace which extends intermittently from the northeastern part of Scranton to a point several miles southwest.

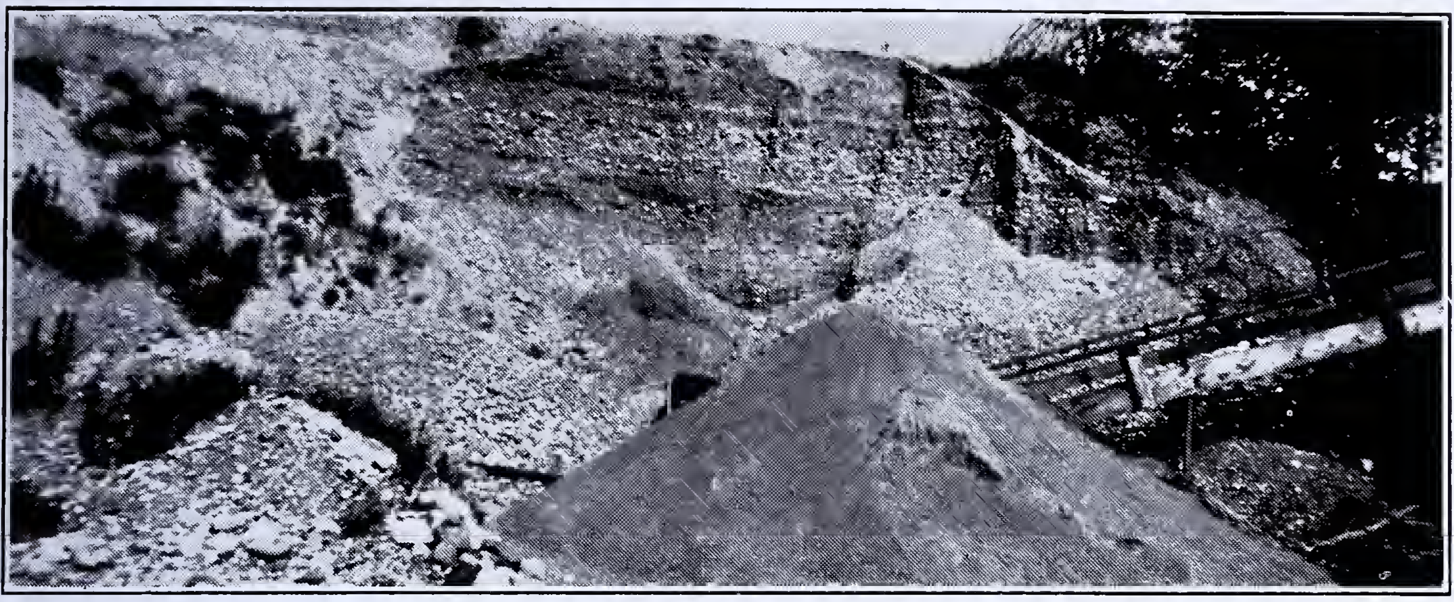
The inner portion of the terrace has a fairly smooth surface while the outer margin is much more irregular, containing numerous shallow pits and kettles, as at Green Ridge and Scranton. Certain of the pits are due to mine subsidence, as is the case at Green Ridge. Most of the pits are true kettles, as is indicated in the terrace where exposed at Birch Street, Scranton. The front of the terrace is irregular and patternless although the extensive mining and building operations may have obliterated any original characteristic features. The terrace slopes gently down valley; the difference in elevation is about 9 feet between the northeastern and southwestern limits, a distance of a little over 4 miles.

The materials comprising the terrace are alternating beds of sand and gravel which appear to be almost entirely local in origin. The individual gravels in the lower beds are usually well rounded while those in the upper beds show only a modicum of rounding. At Providence, Green Ridge and Minooka the deposits are almost all horizontally stratified with coarser beds near the top. (Plate 6, A.) At Scranton and Taylor many of the beds dip sharply toward the valley axis apparently in the form of delta foresets. These inclined beds are commonly truncated and covered by others, some of which dip at various angles toward the valley walls while others are nearly horizontal.

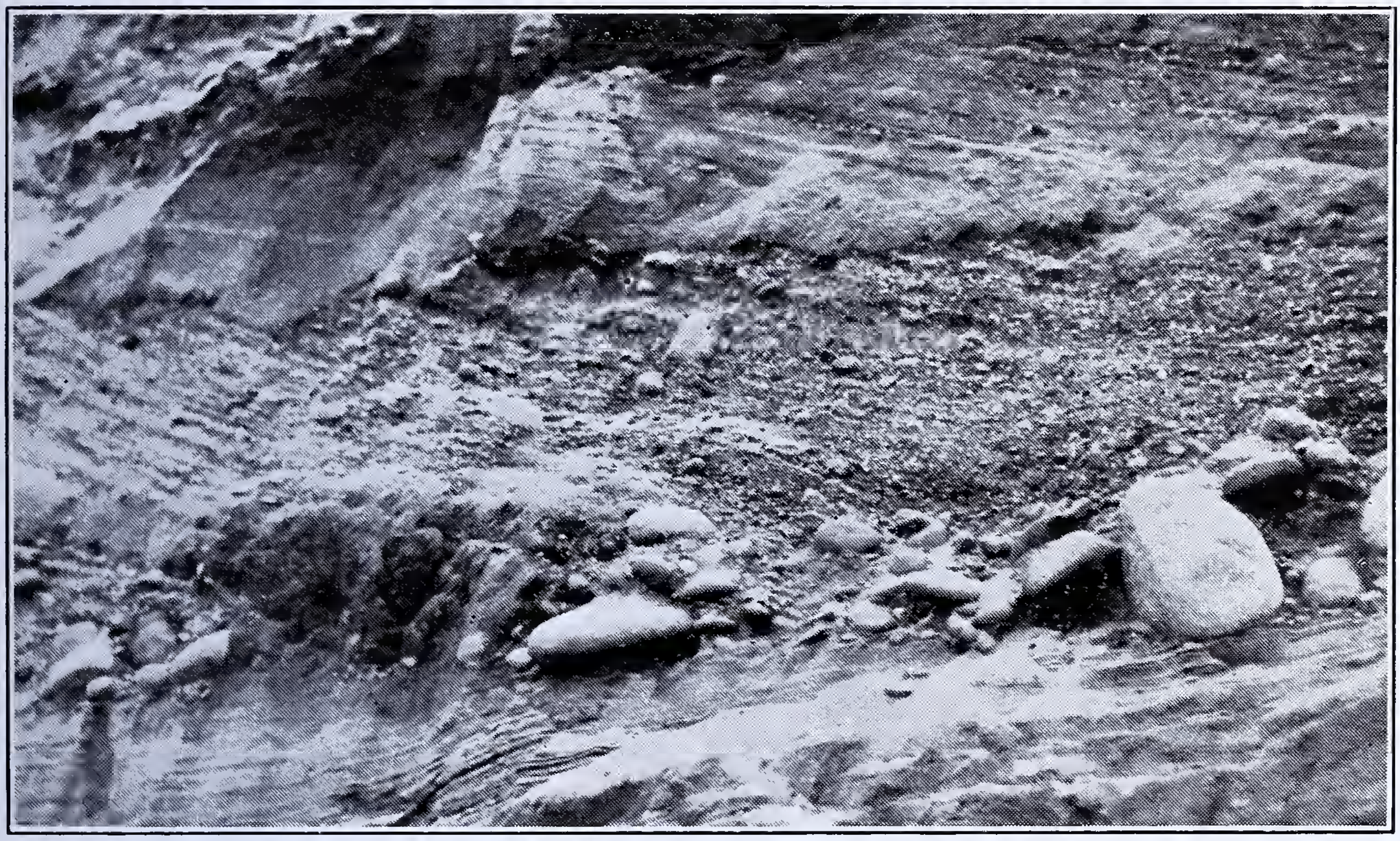
The 720-foot terrace.—A depositional terrace which has an elevation of 720 feet is well developed in the lower end of the Lackawanna Valley. Although postglacial erosion has removed portions of the terrace, the distribution of the terrace segments, their form and slope are of considerable interest. The segments are scattered and dissociated, with no evidence of their formerly having constituted parts of an original continuous terrace. Between the flat-topped terrace units are irregular depressions ranging from a few feet to 15-20 feet in depth and generally trough-like in form. Practically all of these trough-shaped pits are open on the down-valley side and form miniature ravines. The terrace faces fronting the small "inter-terrace" valleys are irregularly shaped but are not suggestive of stream cutting. The valleys are floored with coarse gravel and till. These features are very well shown along the highway leading from Avoca to Old Forge.

The dissociated terrace segments have a very close accordance in summit level. Below Old Forge the terrace slopes gently down valley toward Coxton and the terrace segments in the vicinity of Avoca slope gently south in the present valley of Little Mill Creek.

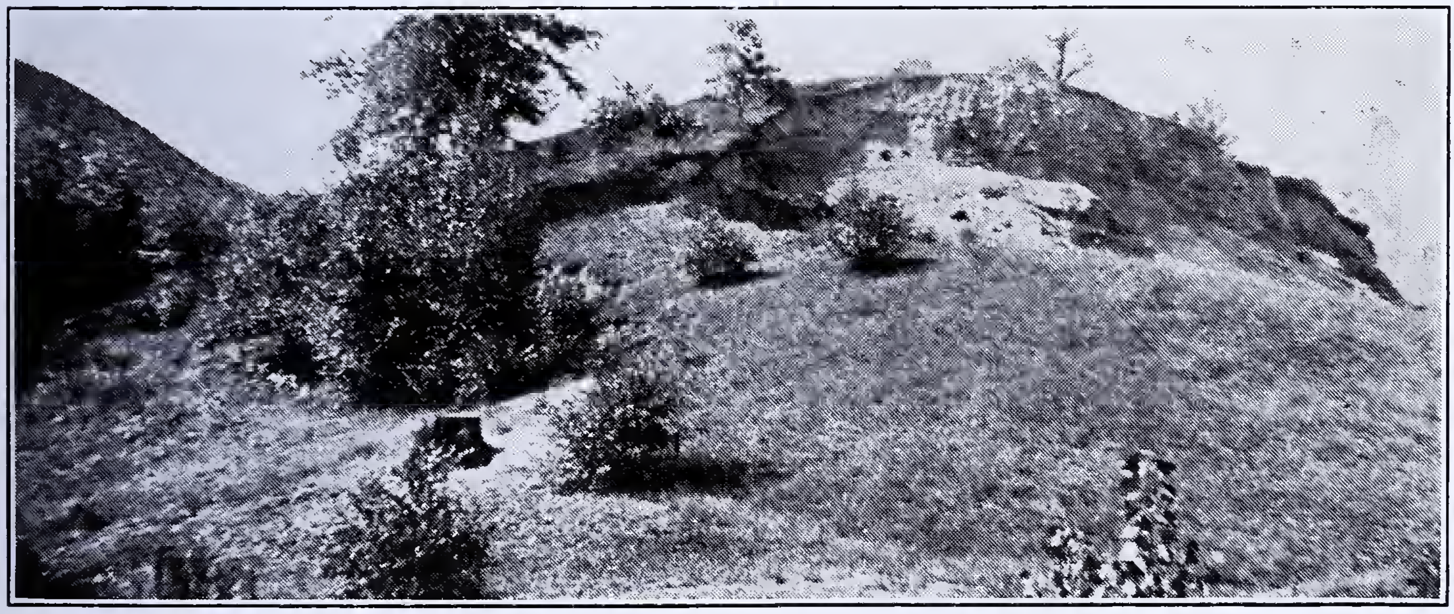
Exposures in sand and gravel pits at Old Forge and Moosic show the upper 2 to 5 feet or more of the terrace is made up of coarse horizontally-bedded gravel. Below these beds comes a series of sand and gravel beds of indefinite thickness in which sand predominates. These beds are highly cross-bedded and although they dip at comparatively low angles they dip in almost every direction. (Plate 6, B C.) Aside from the top series of horizontally-bedded coarse gravel



A. Terrace deposits (flood plain) in Green Ridge section of Scranton. This terrace constitutes the 745-foot level.



B. Detail of a portion of the lower beds in the kame at Moosic.



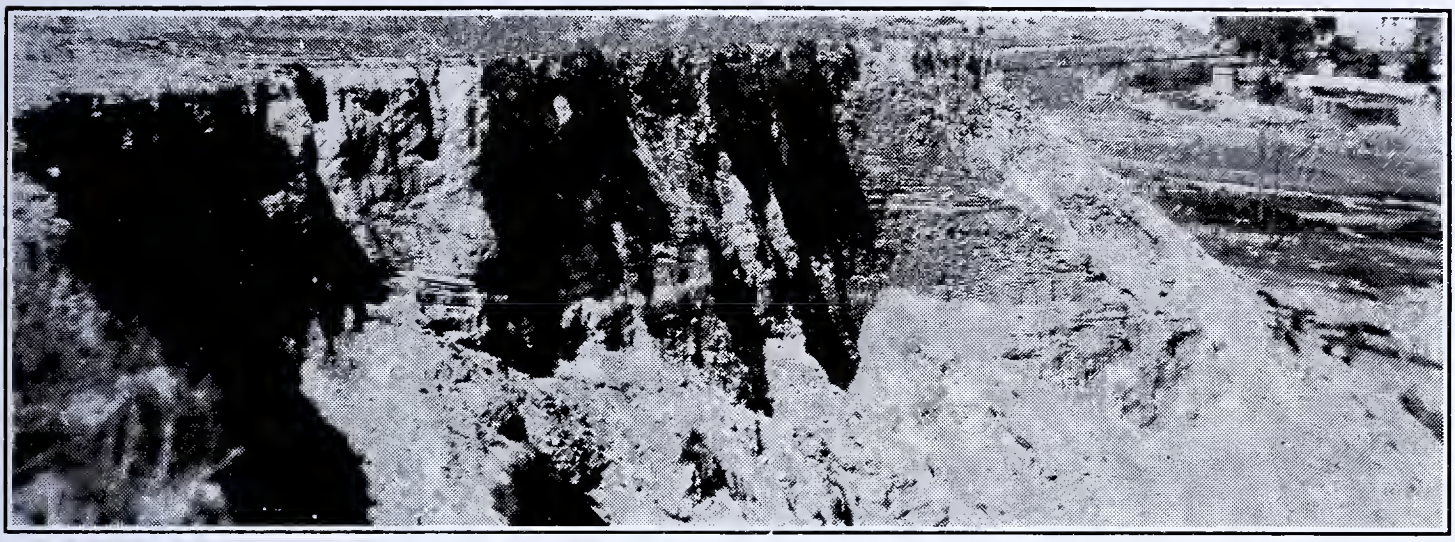
C. Kame terrace at Moosic on east side of the Lackawanna River. Upper coarse beds are nearly horizontal.

no bed or series shows any consistent or persistent dip in any direction for more than a few feet.

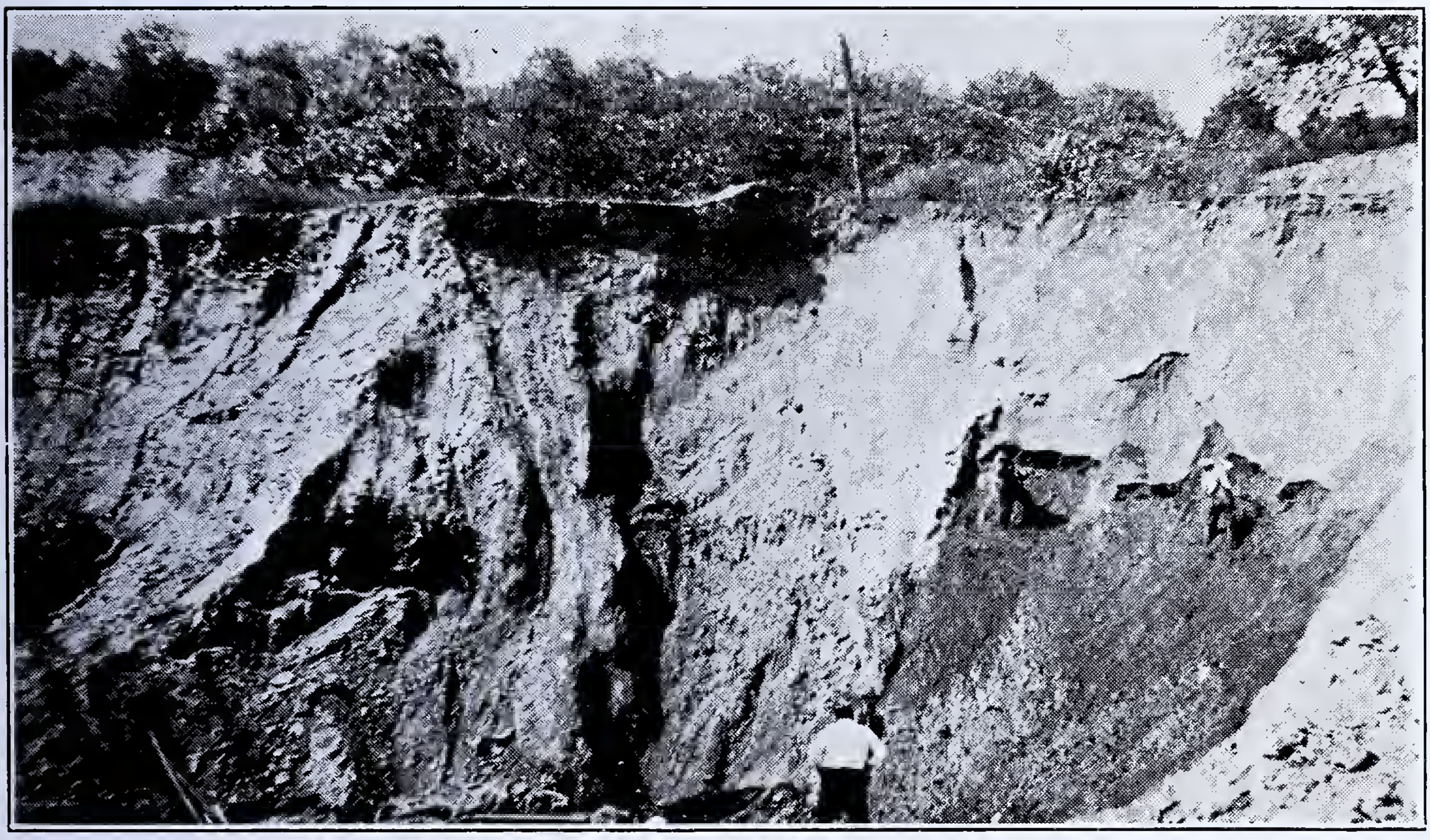
The 685-675-foot terrace.—Remnants of a depositional terrace occur on both sides of the Susquehanna River between Pittston and Nanticoke. At Pittston and West Pittston the terrace rises to an elevation of about 685 feet and is about 10 feet less at the lower end of the valley. The terrace is not continuous on either side of the river; on the northwest side of the valley it can be traced from West Pittston to Plymouth, disappears for a few miles and again appears at West Nanticoke; on the southeast side there are several areas in which the terrace is not represented at the present time, as at Port Griffith, Midvale, Butzbach, etc. The present remnants slope gently down valley but this slope is interrupted frequently either by local slumping or subsidence, as at Larksville, or by partial erosion, as northwest of West Pittston. The down-valley slope is also interrupted by local rises, as at Luzerne, Pringle, and Warrior Run, where lateral streams enter the main valley and have deposited fans, and by irregular rises due to local kame deposits. In the extreme lower end of the valley the terrace has a nearly horizontal surface, as at West Nanticoke and Nanticoke.

Most of the terrace faces are irregular and have suffered greatly from under-cutting on the part of the Susquehanna and minor streams, as at Pittston, while slumping and gullying have altered the original front, as at Larksville and Edwardsville. At Alden, Hanover, Miners Mills and several other localities the terrace front grades into kame deposits whose summits are generally lower than the terrace surface (Plate 7, A.) The human factor has been an important force operating in this region and has seriously disturbed and altered much of the original terrace face.

The material comprising the terrace is very largely stratified sand and gravel. Much of the gravel is fairly well rounded but some of the larger pieces show comparatively slight reworking. Locally erratic boulders and pockets of till are incorporated within the deposits. Although most of the material is local in source there is a small percentage of crystallines which must have come from much farther north. On the southeast side of the valley practically all the material is local in origin except in the area directly east of Nanticoke where crystalline gravels make up an appreciable part of the deposits. On the northwest side of the valley local materials are found to the prac-



A. Cross-bedding in terrace at Miners Mills. The front of the terrace abuts against a kame area.



B. Sand and gravel pit in terrace north of Wyoming, Pa.

tical exclusion of others at and near the mouths of the lateral streams, but in the intervening areas, as at West Pittston and Wyoming, a considerable quantity of foreign gravel may be found.

Deposition of the terrace must have taken place under conditions changing rapidly both as to time and place, judging by the various types of structure encountered. Four major types of structure including flood-plain, delta, kame and a type best described as tumultuous may be seen, and usually at least two of the above will be seen at any exposure. The terrace on the northwest side of the valley illustrates all these varieties of structure. The simplest structure, in which horizontal bedding predominates, is illustrated at West Pittston and Exeter where the horizontally-laid deposits contain much coarser material. In an exposure in a sand and gravel pit at Wyoming the structure might best be described as tumultuous for there seems to be no rhyme or reason to account for the disorder of the bedding. Certain beds dip sharply toward the valley wall while others dip just as sharply toward the valley axis. Till pockets, clay lenses, and many boulders are incorporated freely within the deposit. Thick beds of sand truncating other dipping beds further complicate the structure. The upper beds comprising from 3 to 5 feet of coarse gravel are horizontally stratified. (Plate 7, B.)

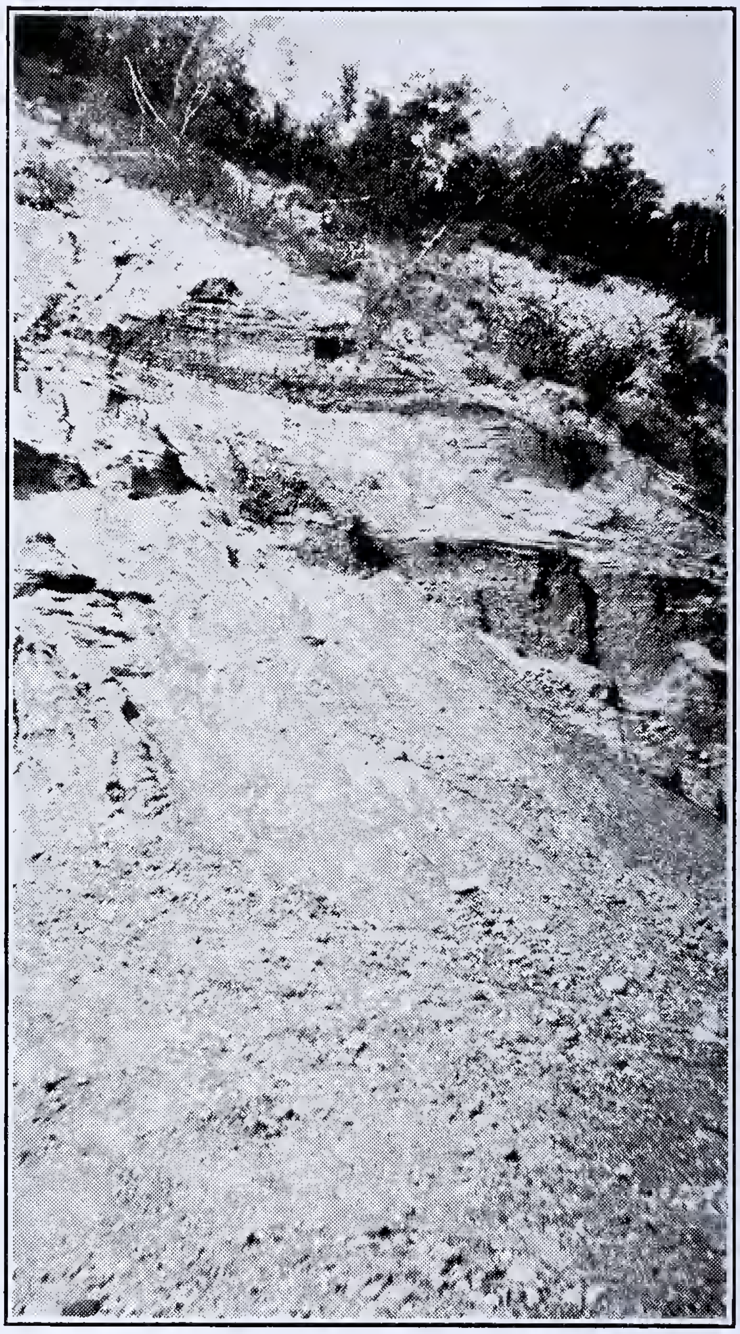
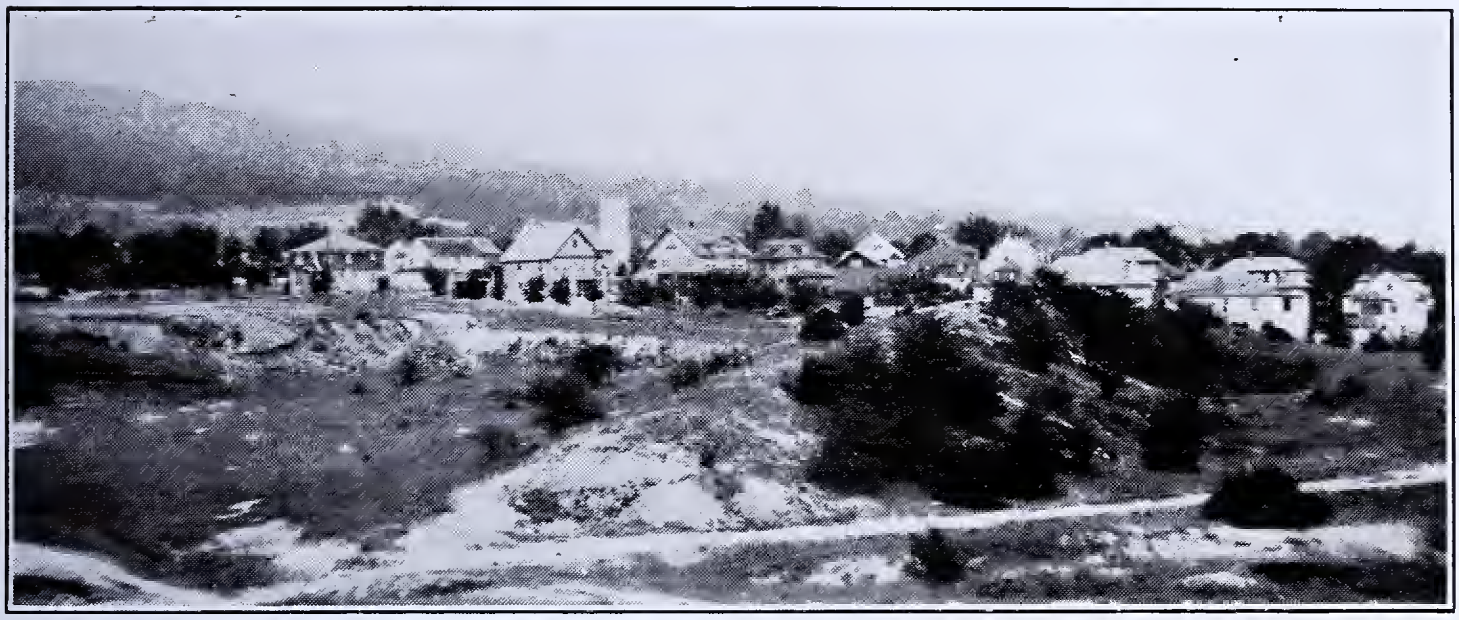
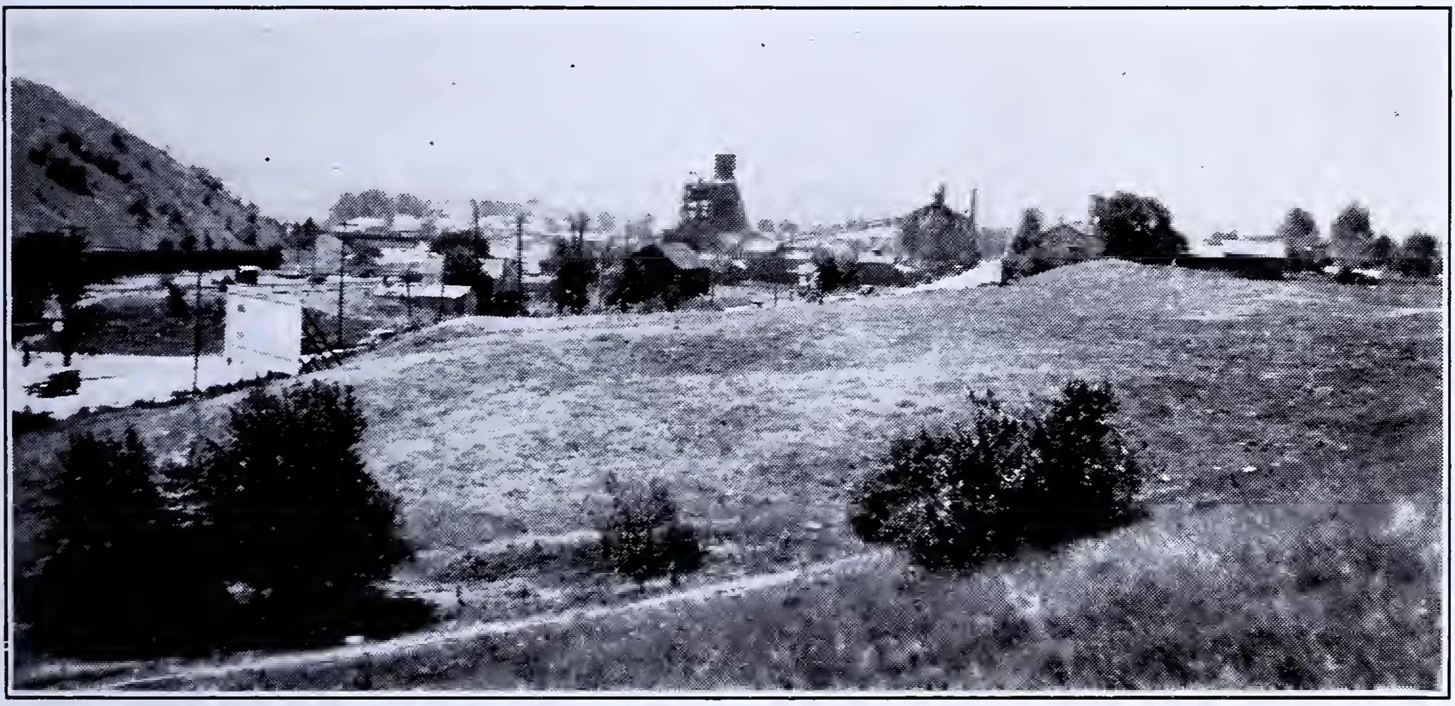


Plate 8. Delta foresets in the terrace at Dickville.

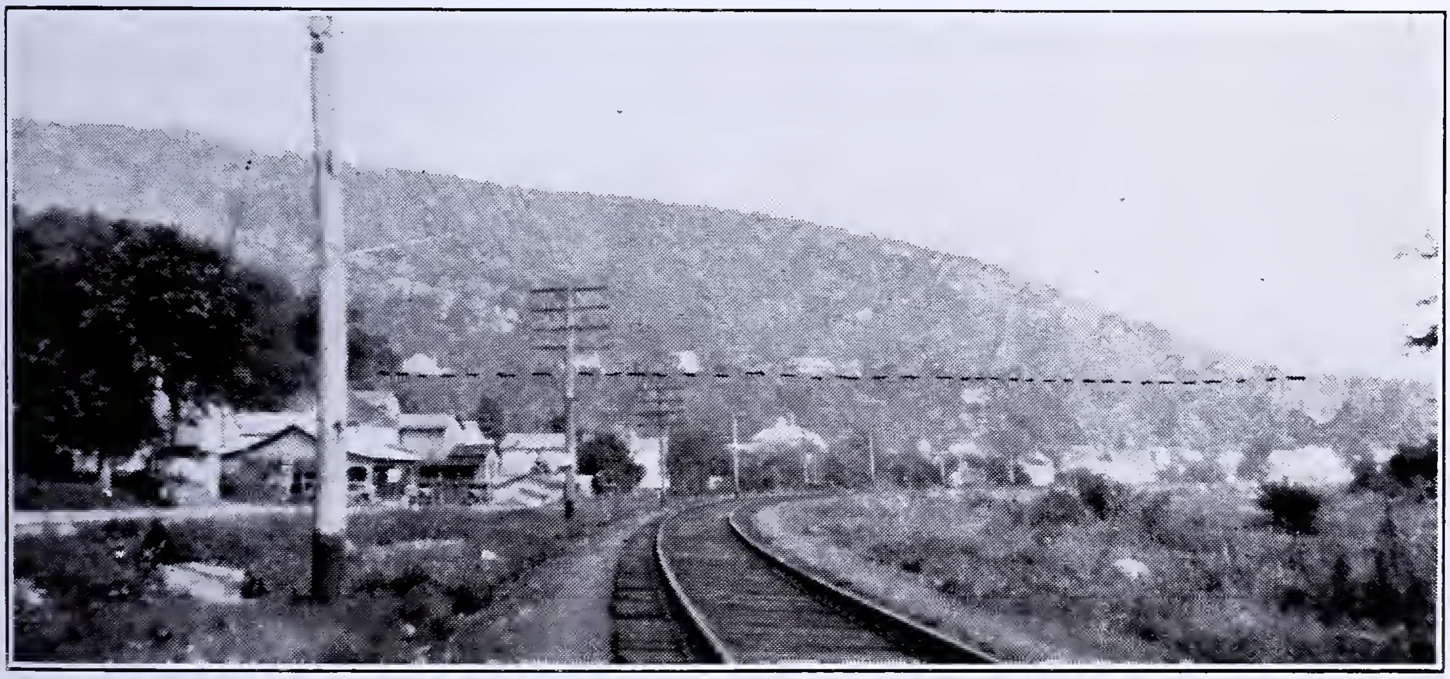
At Dickville and Maltby the deposits consist mostly of alternating series of sand and fine gravel beds. Most of these beds dip sharply toward the valley axis in the general manner of delta foresets. The delta structure has been complicated by a series of sand and gravel



A. Kame (esker) between Blakely and Dickson City.



B. Kame area between Blakely and Peckville. Kettle hole in middle ground.



C. Tilbury terrace, West Nanticoke, Pa. A delta developed in the lee of a protecting rock spur.

beds which dip toward the valley sides and truncate portions of the delta foresets. Sand and clay lenses are a minor constituent. (Plate 8) Other localities in which delta foresets predominate are at Edwardsville, West Nanticoke, and Hunlock Creek. The top beds generally are horizontally stratified and commonly are coarser than the dipping lower beds.

Kame structure in which cross-bedding predominates is found in the deposits in the vicinity of Parsons and Miners Mills. The structure and form of the terrace in that area is quite similar to the 720-foot terrace at Avoca and Moosic. The intricately cross-bedded lower sands and gravels are capped by horizontally-bedded coarse gravel.

The 670-foot terrace.—The 670-foot terrace is a depositional form restricted to the lower few miles of the Lackawanna Valley. The terrace slopes gently down valley from Taylor to Coxton at the upper end of Wyoming Valley. The surface of the terrace is generally smooth except in the vicinity of Taylor where it is knobbed with low hummocks and pitted with shallow kettles. Near the mouth of Keyser Creek in the vicinity of Taylor the deposits are cross-bedded with a series of coarse horizontally stratified gravels capping them. At Avoca the structure is similar to that at Taylor but at Old Forge, Duryea, and Coxton where the terrace forms the first step above the present river plain the deposits are largely coarse gravel horizontally stratified.

Kames Northeast of Scranton

Stratified deposits of sand and gravel unrelated to any specific terrace levels occur extensively in the Lackawanna Valley, northeast of Scranton. Most of these deposits are kames and represent deposition along the flanks of the ice tongue as it lingered in the central part of the valley. The principal kame areas lie between Dickson City and Peckville on the northwest side of the river and between Throop and Olyphant on the southeast side. In these areas the lower mountain slopes are knobbed with low rounded hills and pitted with shallow kettles. The highest knobs rise about 50 feet above the main highway and grade upward into fairly smooth till-covered slopes on the mountain side. From the west end of Blakely to the east end of Dickson City there is a well-developed esker which can be traced for over 2000 feet. This esker lies about 150 feet north of the main highway and has been breached by a branch railroad which runs to the Johnson No. 2 Colliery at Dickson City. (Plate 9, A and B.)

Summary of Terrace Characteristics

The two highest terraces previously described are developed on rock and are not concerned in the following summary. The important characteristics of the terraces which throw considerable light on their mode of origin are indicated below.

Distribution and form.—1. The terrace surfaces show in general a slight downstream slope. This inclination is interrupted in several different ways.

(a) By lowering of the terrace surface either through mine subsidence or partial removal by normal erosion.

(b) By raising the local level either through the development of fans opposite the mouths of lateral streams or by kame deposits higher than the normal level.

(c) By the development of a nearly horizontal surface in the lower end of the Wyoming Valley.

2. The terrace tops are very rarely smooth surfaces but commonly are irregular.

3. The terrace remnants fringe the mountains on both sides of the valley and have the same levels except as explained in (1).

4. Most of the terrace fronts observed have been produced through postglacial erosional processes or through the work of man, and represent destructional rather than constructional forms.

5. The more irregular portions of the terrace surfaces commonly lie close to the terrace front.

Composition and structure.—1. Jumbled and irregular stratification characteristic of the cut and fill action common to strong stream currents, together with inclusions of clay and till pockets, predominates in most of the terrace exposures examined.

2. Definite delta foreset beds prevail in a small percentage, possibly 10 percent, of the terrace exposures noted, but nowhere are they present to the exclusion of some cross-bedding.

3. Coarse gravel usually sub-rounded and horizontally stratified commonly forms the capping series in most exposures.

4. Imbrication of the coarse gravel in the upper horizontally stratified sediments in the lower end of the Wyoming Valley indicates that they represent topset delta beds; imbrication in most other places suggests that the currents responsible for deposition moved longitudinally down the valley.

5. Horizontal stratification of poorly graded sands and gravels is present in some localities to the exclusion of any other definite structure.

6. Local dissociated terrace segments possess the typical cross-bedding and lensing of sands and fine gravels characteristic of kame deposits.

7. Well-rounded crystalline gravels occur along the northwest side of the valley except where mountain streams debouch; they occur also in the southeast side between Wilkes-Barre and Nanticoke.

8. True deltaic structure is present only in those terraces developed in the lee of a rock spur.

Interpretation of the Terraces

The marginal terraces of the Wyoming-Lackawanna Valley have very much the same form and origin as those described by Salisbury[10] from the glaciated area of New Jersey.

> "In mountainous regions, where the friction of movement was great, it sometimes happened that considerable masses of ice became stagnant during the dissolution of the ice-sheet . . . Ultimately some of the valley ice lost its motion, but even after it became stagnant it exerted an important, though passive, influence in determining the position of stratified drift deposits, and the forms which they assumed."

Explanation then follows as to the manner by which the drainage flanking the ice mass gives rise to deposits of stratified drift banked against the ice.

> "After the ice had melted, these deposits of stratified drift constituted a sort of constructive terrace against the valley slope . . . A kame terrace, then, is a terrace of sand and gravel, deposited by a glacial stream between valley ice (generally stagnant) and the rock slope of the valley. More or less isolated kames are sometimes associated with kame terraces."

The characteristics of the Wyoming-Lackawanna terraces strongly suggest that fluviatile deposition was mainly responsible for their development and deposition under lacustrine conditions played but a minor part. The slight downstream slope of the terrace surfaces is highly significant of fluviatile deposition. None of the other characteristics of distribution and form are critical inasmuch as they may apply to either fluviatile or ponded water deposits.

The composition and structure of the terrace deposits are definitely characteristic of fluviatile control. Certainly the features 1, 3, 4, 5, and 6, as summed up in the previous section dealing with characteristics of composition and structure, are definite indications of strong stream currents. The 7th characteristic, distribution of the rounded crystalline material, is regarded as highly significant. These crystalline gravels are found in abundance in the terraces in the Wyoming Valley but are not in evidence in the Lackawanna Valley terraces. Along the northwest side of the valley they are abundant except where transverse mountain streams have furnished the vast bulk of the deposits; on the southeast side the rounded crystalline gravels occur between Wilkes-Barre and Nanticoke. This distribution and character of the crystalline gravels strongly suggest that (1) they were brought in only through the gap at Pittston, (2) they were brought in mainly by running water, and (3) their distribution on both sides of the Wyoming Valley was accomplished by running water and not by ice.

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[10] R. D. Salisbury, Glacial Geology of New Jersey; N. J. Geol. Survey, vol. 5, 1902, pp. 121-123.

If the ice sheet were mainly responsible for the transportation of these crystalline gravels they might logically be expected to occur also in the Lackawanna Valley. The degree of rounding is indicative of extensive transportation by water and their distribution on both sides of the valley is taken as evidence of the former presence of strong stream currents.

It is true that considerable crystalline material might well be carried by ice across the valley and up the mountain slope on the opposite side. With the melting of the ice the material might be expected to be carried down into the valley by mountain streams where it could be incorporated as terrace material. The fact that all of the crystalline gravels found are very well rounded suggests, however, that transportation by running water rather than ice was the dominant agent.

The presence of definite delta foresets in a small percentage of the deposits indicates that deposition in narrow marginal lakes affected by currents played a minor part in building the terraces. Again the majority of true delta forms are found in the lee of a protecting rock spur and deposition may well have been in an embayment of the valley, rather than in an extensive lake. The imbrication of the coarse gravel in the upper beds and the development of a horizontal terrace surface in the lower end of the Wyoming Valley are regarded as evidence favoring the development of a local lake level in this area.

It is believed that the evidence in the field points to the following interpretation of the terraces. During the latter stages of the Glacial epoch when the ice no longer covered the mountains, there must have remained in the nearly enclosed valley a huge block of ice some hundreds of feet thick. Streams coursing down the mountain sides carried considerable quantities of wash recently left by the melted ice. Much of this debris must have been lodged, somewhat rearranged as to texture and stratification, along the edges of the ice block. Streams must have flowed parallel to the strike of the valley between the ice and the mountain wall and other streams must have come from the ice in the valley itself. Thus three different currents were engaged in adding to and rearranging materials deposited between the ice and the valley sidewall.

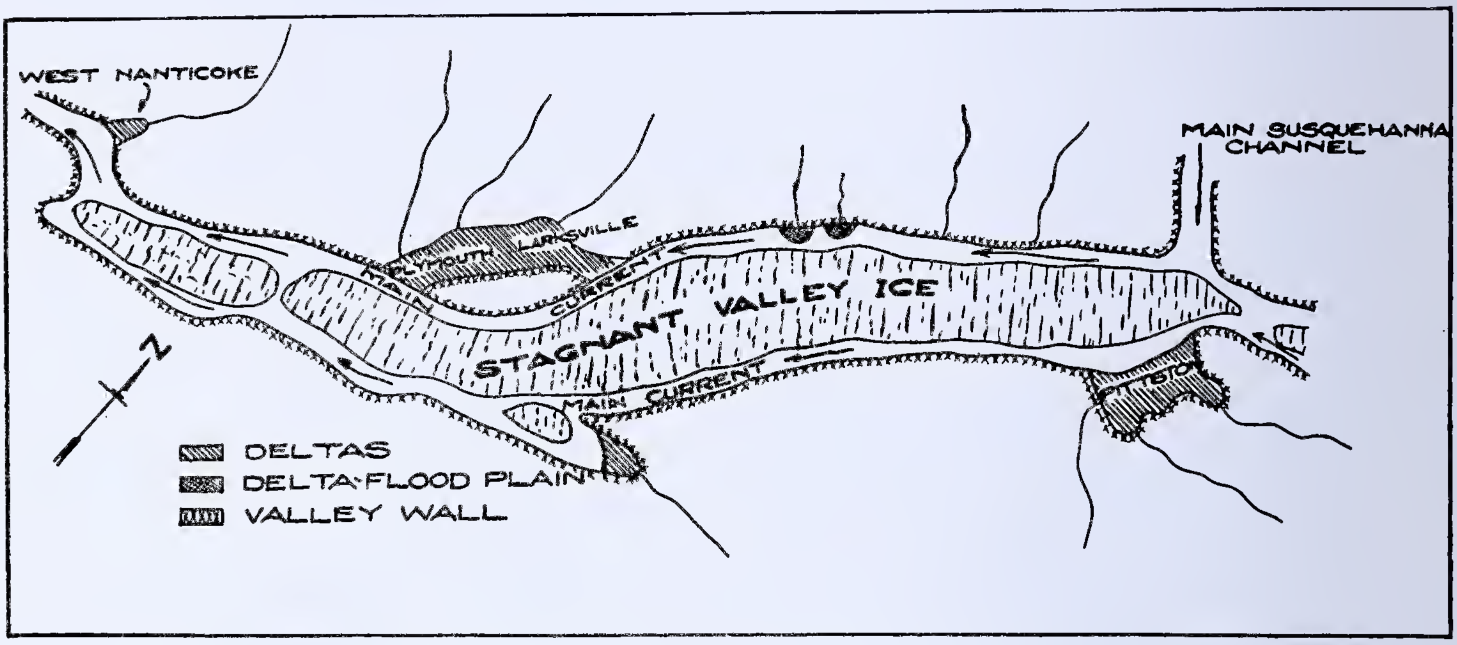

Figure 45. Development of deltas in lee of protecting rock spurs.

It must be understood that drainage did not necessarily come down both sides of the valley throughout its entire course. Irregularities in the ice and irregularities of the valley sides might allow discontinuous deposition. Where prominent rock spurs extended into the valley nearly current-free waters might be expected in their lee. (Figure 45.) Where transverse mountain streams entered such protected embayments deltaic deposits might be expected to occur. It is in precisely such rock protected embayments that the important deltaic forms of the region are found, notably at West Nanticoke, at Larksville, and at Pittston. (Plate 9, C.)

Temporary protection afforded by irregularities in the ice might likewise produce local short-lived embayments in which mountain streams might build deltas. With melting or movement of the ice, protection would end and current bedded deposits would be mixed with the deltaic forms. Thus the mixture of deltaic and current bedded forms seen at Maltby, Dickville, and Scranton might be constructed.

The net result of these conditions would be the establishment of terraces on each side of the ice block which were partly of slack-water origin and partly current or channel deposits. In embayments mountain streams would build true deltas. True deltas would hardly form elsewhere, for currents coming from the ice, sometimes at angles of 180 degrees to the direction of mountain streams, would tend to build deltas whose foreset beds dipped in the opposite direction. The down-valley currents would behave somewhat as flood plain currents do, cutting here and filling there, completely changing the character of the previously deposited material. As a result, the deposits, while ultimately presenting a general terrace level on both sides of the valley, need never have been connected except locally by channels developed and maintained where crevasses existed in the valley ice. The general level on both sides of the valley would thus be the same, while deposits of a minor nature would be left in the central portion of the valley. (Figure 46.)

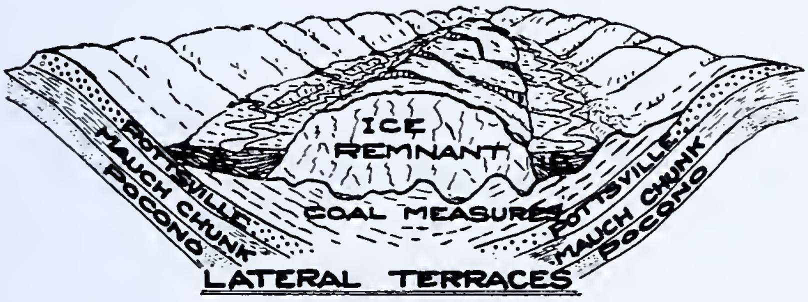

Figure 46. Mode of origin of the lateral terraces.

Origin of the horizontally stratified coarse gravel caps

Most of the upper portions of the terraces in this region reveal an accumulation of coarse gravel poorly rounded and mixed with various amounts of poorly sorted finer material. This feature is characteristic of kames and certain terraces in other regions and has led to various suggestions as to its mode of origin. One suggestion considers the coarse material as having been dropped near the mouths of ice tunnels while the finer material was carried away by the outflowing water. A second is that the gravel accumulation is a secondary feature, most of the finer material originally mixed with the gravel having either been blown away, washed down to a lower level, or carried to nearby streams. A third interpretation considers this layer to represent till somewhat reworked and indicating local readvance of the ice.

In the Wyoming-Lackawanna area this coarse upper layer is common to both the deltaic and fluvial forms. In the deltaic forms it quite clearly represents the topset beds; in the fluvial deposits it is interpreted as the type of deposition that would normally occur when in the final stages of glacial dissipation melt water issuing from the ice plus normal drainage brought in deposits of mixed character and possibly to some extent reworked the terrace tops with resulting concentration of coarse debris.

The Pittston-Nanticoke Lake

In the last stage of the Glacial epoch, perhaps while there was some small remnant of ice in the valley, there may have been a lake several miles wide extending from above Pittston to Nanticoke. This lake was a possibility due to the fact that glaciation had overdeepened the valley, so it may have existed for a short time as a finger or trough lake. If, however, the melting of the ice block in the central valley was fairly slow, the "buried valley" may have been filled as rapidly as the ice melted; hence, there is no assurance that a lake actually existed.